SEPTEMBER, 1961

Welding Journal

See page 934

IN THIS ISSUE

Welding Aluminum with Large Diameter Fillers..... 917
Use of Welding to Produce Intricate Shapes..... 928
Corrugated Monel Heat Exchanger..... 934
Factors Influencing Welding Arc Stability..... 942
Cracking in Submerged-Arc Welds in Constructional Steels.... 385-s
Fabrication of High Strength 2¼% Cr–1% Mo Materials..... 393-s
Cooling of Carbon Steels for Pressure Vessels..... 400-s
Evaluation of Sheet Fracture Toughness..... 405-s
Welding Nodular Iron Without Post-Weld Annealing..... 417-s
Superalloy Multilayer Sandwich Structures..... 423-s
Index to Advertisers..... 1006

1961 NATIONAL FALL MEETING

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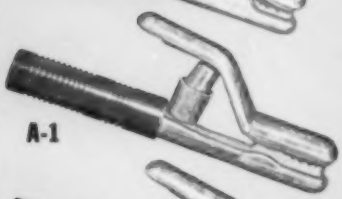

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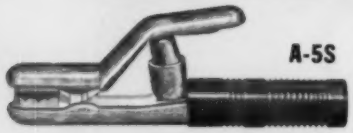

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350	1/4"	A-1	7.15		
450	5/16"	A-3	8.90		
500	3/8"	A-3S	9.20		
300	1/4"	ST-3	7.90	As above, with Sealed-Tight Connection	
450	3/8"	ST-5	9.20		
300	1/4"	A-W	7.80	Featherlight Holders	ALUMINUM ALLOY
400	5/16"	A-5S	9.10		
200	5/32"	JH-2	7.50	Streamlined Featherlight Holders	
300	1/4"	JH-3	8.60		
300	1/4"	B-1	5.15	Economy Holders	98% COPPER
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400	5/32"	B-4	5.00		

*All Prices Lower in Quantities

STREAMLINED HOLDERS

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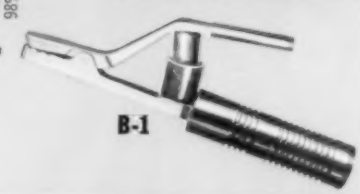

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HOLDER CLASS	MODEL NUMBER	ELECTRODE DIAMETER	AMPERAGE	CABLE SIZE	DUTY CYCLE
SMALL	JH-1	5/32"	150 200	2 1	50%
MEDIUM	AW-C	7/32"	250 300	1 1/0	50%
	A-1 & ST-3	1/4"	300 350	1/0 2/0	50%
LARGE	A-3 & ST-5	3/8"	375 450	2/0 3/0	65%
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VOLUME 40 • NUMBER 9 • SEPTEMBER 1961

Welding Journal

Technical Papers Items and Reports

Gas Metal-Arc Welding Aluminum with Large Diameter Fillers, by James A. Liptak 917
Use of Welding to Produce Intricate Shapes, by Steel Founders' Society 928
Corrugated Monel Heat Exchanger, by J. F. O'Connell, N. J. Ritchey and J. C. Stewart 934
Electrical and Metallurgical Factors Influencing Welding Arc Stability, by Jerry E. Ginn 942

Practical Welder and Designer

Skill with a Skillet, by R. W. Brandenstein and J. A. Wendel 947
Nickel-Silver Alloy with Automatic Fluxing System Beats Production Problems, by Lee S. Wade 948
Heavy Plate Girders for Ohio Thruway Welded by Submerged-Arc Techniques, by Paul L. Holden 950

Society and Related Events

Press-Time News 906
Welding Zones 908
World-Wide Welding News 910
Editorial—Staying Ahead of the Future, by R. C. Fernley 915
Society News 951
Technical Papers Sessions—1961 AWS National Fall Meeting 957
Section News and Events 968
New Members 971
News of the Industry 972
Abstracts of Current Patents 978
Current Welding Literature 979
Personnel 980
Employment Service Bulletin 985
New Literature 986
New Products 992
Reader Information Card 1005
Index to Advertisers 1006

Welding Research Supplement

Study of the Causes of Cracking in Submerged-Arc Welds in Constructional Alloy Steels, by M. D. Randall, R. E. Monroe and H. J. Nichols 385-s
European Welding Research, by Gerard E. Claussen 392-s
Properties and Fabrication of High Strength 2¼% Chromium–1% Molybdenum Materials, by R. C. Griffin and G. N. Emmanuel 393-s
Accelerated Cooling of Carbon Steels for Pressure Vessels, by D. A. Canonico, E. H. Kottcamp and R. D. Stout 400-s
Sheet Fracture Toughness Evaluated by Charpy Impact and Slow Bend, by George M. Orner and Carl E. Hartbower 405-s
Welding Nodular Iron Without Post-Weld Annealing, by R. C. Bates and F. J. Morley, Jr. 417-s
Superalloy Multilayer Sandwich Structures for Application to 1800° F, by H. Smallen 423-s

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PRESS-TIME NEWS ...about ...People ...Welding ...Products

SNT Schedules Conference

Inspection of steam power and nuclear power plant components will be the subject of a one-day conference scheduled by the Society for Nondestructive Testing for Wednesday, October 25, in Cobo Convention Hall in Detroit, Mich. The conference is sponsored by the Society's Utilities Committee on which Mr. Helmut Thielsch of Grinnell Co. serves as chairman.

The conference is to be part of the Annual Fall Meeting Program held by SNT concurrently with meetings of the American Society for Metals, and the American Institute of Mining and Metallurgical Engineers.

Air Force Sponsors Welding Symposium

The Air Force Systems Command, Space Systems Division, recently sponsored an ultrasonic welding presentation in California. The purpose of the meeting was to introduce ultrasonic welding to ballistic missile and space system contractors, and the Air Force invitation commented that ultrasonic welding was becoming "a vital metal joining technique . . . permitting designs which were previously considered nonproducible."

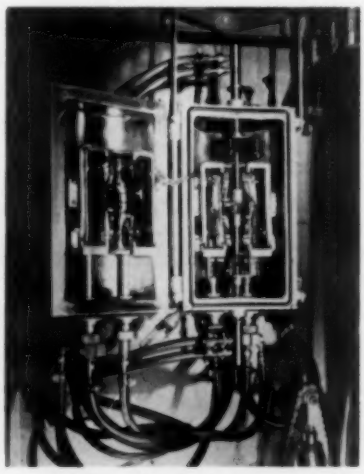
The meeting recognized the pioneering contributions of Aeroprojects Inc. and its subsidiary, Sonobond Corp., West Chester, Pa., producers of commercial ultrasonic metal joining equipment.

At the meeting, Francis Becker, Procurement and Production Office of the Space Systems Div., stressed the progress that Russians were making in the field. While Russian published literature has not demonstrated progress approaching that in the United States, the level of effort appears to be extremely high and therefore should be taken seriously.

Crucible Steel Installs Test Furnaces

Crucible Steel Co. of America recently installed two unique vacuum tensile test furnaces at its Central Research Laboratory in Pittsburgh to determine strengths of space age metals under conditions designed to simulate those hundreds of miles above earth.

The furnaces are a development of the High Vacuum Equipment Corp., Hingham, Mass. and are designed for rapidly bringing the sample to desired conditions of vacuum and temperature. Metal evaluation studies to date involve creep and tensile testing of refractory metals at 3000° F as well as heat treatment at temperatures up to 3500° F at a vacuum from 1 x 10^{-4} to 1 x 10^{-5} mm Hg.



Crucible Steel is using the system to ascertain short time ultimate strengths of various materials; measuring elongation, and stress rupture point.

McKay Picks Crouch

John C. Crouch has been elected vice president of The McKay Co., Pittsburgh, Pa.

Prior to his election, Mr. Crouch served as assistant secretary and personnel manager for McKay. President James C. McKay said that Mr. Crouch will continue as assistant secretary but, in his new position, will devote time to general company business with emphasis on personnel and public relations matters.

J. C. Crouch

Mr. Crouch joined McKay in 1936 as assistant controller. He previously had attended the University of Pittsburgh's School of Business Administration.

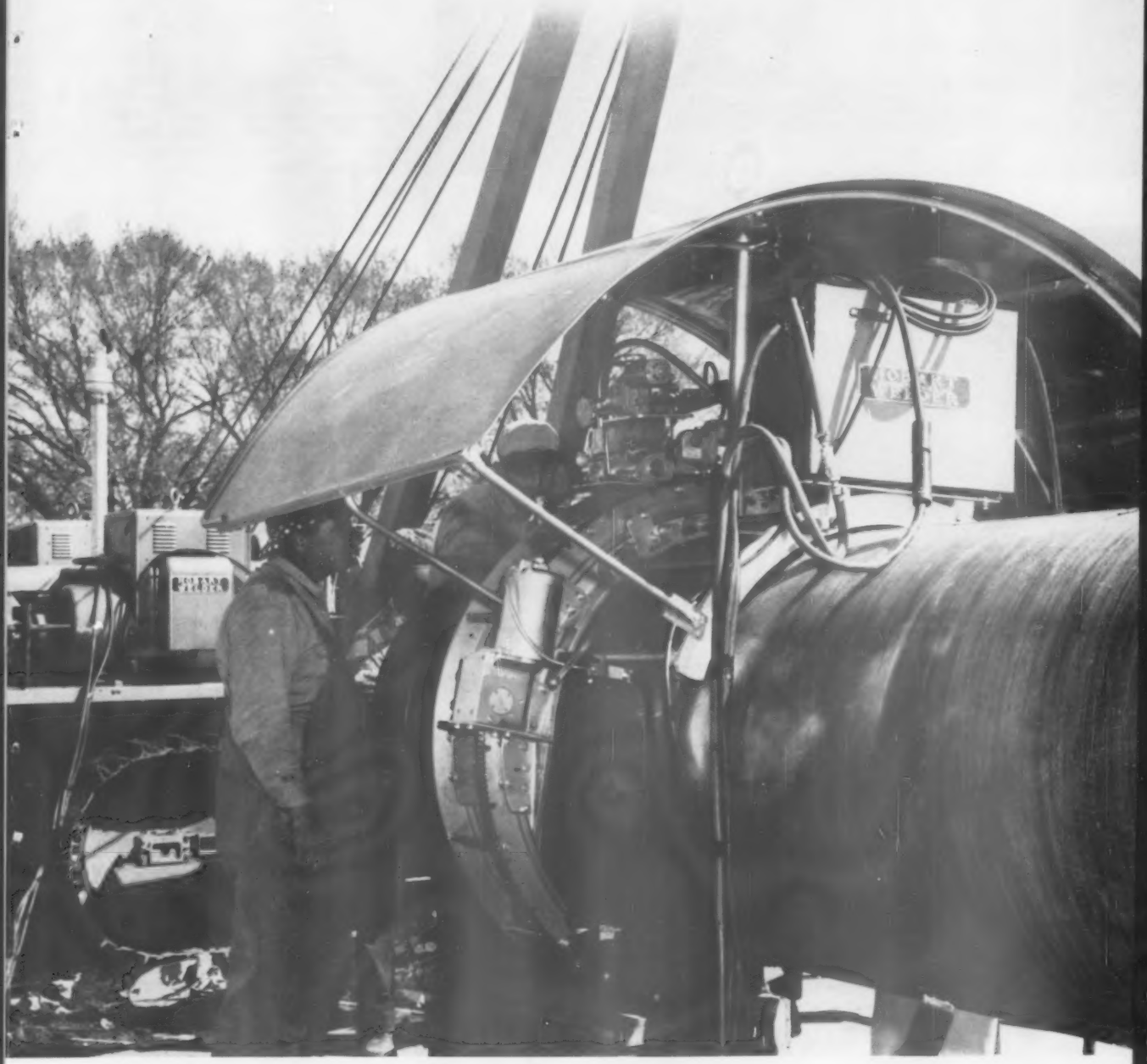
Linde Names Research Manager

Dr. Milton Stern has been appointed manager of research of the Speedway, Indiana Research Laboratories, it was recently announced by W. B. Nicholson, president of Linde Co., Div. of Union Carbide Corp. Dr. Stern joined Union Carbide Metals Co. at Niagara Falls in 1954 and has been with Linde since March 1960, as Assistant Manager of Research, Speedway Laboratories.

In his new position, Dr. Stern will be responsible for all research activities at the Speedway Laboratories.

Welding 36″ FIXED *pipe automatically!*

. . . this is a major welding break-through that greatly reduces welding costs on cross country pipelines. 500 ampere Hobart *Micro-wire* units with specialized feeder controls and specially controlled analysis wire produce X-ray quality welding in all positions and eliminate weld cleaning. These fully automatic units are now in service at Burney, California on a 36″, 500 mile gas line. The equipment was designed by the H. C. Price Company in conjunction with Crose-Perrault and Hobart Brothers Company. For more complete information, write Hobart Brothers Company, Box WJ-91, Troy, Ohio.



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WELDING ZONES

Stairway railing in the Brookings Institution Center for Advanced Study, Washington, D. C., made of Type 304 stainless steel and fabricated with the stainless steel welding rods using submerged-arc process. (Courtesy Allegheny Ludlum Steel Corp.)

Conical 180-ft long shock tube that can simulate the blast waves generated by simultaneously firing six of the most destructive blockbusters ever dropped during World War II. (Courtesy U.S. Naval Ordnance Laboratory, White Oak, Silver Spring, Md)

Electric-arc welding of 4-D wrought iron, 12-in. diam domestic water line scheduled for use in a new brewery recently opened by Carling Brewing Co. Welding is speeded through fluxing action of iron silicate fibers. (Courtesy A. M. Byers Co.)

Chlorinator tank—ringed with titanium heat transfer coil 1-ft, 4 in. high and 5 ft diam—is the heart of calcium hypochlorite production at Pennsalt Chemicals Corp., Wyandotte Mich. (Courtesy Titanium Metals Corp. of America)

YOU CAN'T ALWAYS WELD BY THE BOOK

Books don't pinpoint all the welding variables. Complex joints. Fussy metals. Tricky fixturing. These variables create problems, more and more of which are being solved by the utilization of *inert-gas* and *consumable-electrode* welding processes . . . combined with pioneering *experience*—the kind you find at Linde Company's Electric Welding Laboratory. Everyone claims "unmatched" research and development facilities. We have 74 fully-equipped *electric welding* stations . . . 100-plus *electric welding* specialists who spend 62% of their time on customers' problems, much of it in customers' plants, all of it free-of-charge. We are spending 3.5 million dollars every year to develop new processes, improve existing ones, and support customer-assistance programs. Here, in the past 25 years, LINDE has developed eleven major inert-gas and consumable-electrode concepts—from *submerged-arc* to *short-arc*—far more than any other manufacturer. The source of these developments—the LINDE Electric Welding Laboratory—is always ready to work for you. And since we market *every type* of inert-gas and consumable-electrode equipment, your problem receives the authoritative, yet impartial study you need.

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WORLD-WIDE WELDING NEWS

By Gerard E. Claussen

BELGIUM

In its issue No. 4 of 1960 the *Belgian Revue de la Soudure* contains the following articles:

- American developments and equipment for consumable electrode welding in argon are reviewed.
- The electron beam welding of aluminum cans for uranium fuel elements is described. The equipment at the Research Center for Nuclear Energy in Mol, Belgium, uses 30kv at 50ma. The focal spot diameter is between 0.016 and 0.028 in.
- Radiators for home heating are made from mild sheet steel stampings welded together in groups of 15 using 15 oxyacetylene torches.

CZECHOSLOVAKIA

Zvarunie for January 1961 contains the following articles:

- The torsion fatigue strength of spot-welded steel disk wheels for automobiles was higher than that of riveted wheels.
- From the standpoint of arc welding, it was found that 5% Cr steels containing 0.5% Mo were the same as with 1% W.
- A flash welder for boiler tubing is described.

The contents in the February 1961 issue are:

- A specimen for assessing the gas weldability of steel sheet is proposed. The weld is subjected to an Erichsen Test.
- Equipment for the semisubmerged-arc welding of aluminum is described. The flux consists of 20% NaCl, 50% KCl, 30% Cryolite. To weld aluminum $^{3}/_{8}$ in. thick, the electrode is $^{1}/_{16}$ in. diam, flux depth is $^{5}/_{32}$ in., current is 275 amp, 28 v and the travel speed is 15 ipm. Single-pass butt welds can be made in plate $^{3}/_{4}$ in. thick at 460 amp, 28 v and $8^{1}/_{2}$ ipm.

HOLLAND

The January 1961 issue of *Lastechniek* describes the successful welding of cupro-nickel heat exchanger tubes to a steel header with Incoweld A and Monel 140 electrodes. Abstracts are given of five papers to be read at a boiler construction conference in Antwerp, Feb. 23, 1961. One paper reports internal pressure fatigue tests on 18 vessels 2 ft diam, $^{3}/_{4}$ in. thick. A fatigue stress of 33,000 psi or more was withstood for 100,000 cycles.

POLAND

The November 1960 issue of the Polish welding magazine *Przeglad Spawalnictwa* contains the first part of a review article on adhesives for joining metals, which is continued in the December 1960 and January 1961 issues. The testing of glued joints and the distribution of stress in lap joints are discussed in detail.

The November and December 1960 issues contain a description of an optical enlarger for projecting tracings of parts to be flame cut. The enlarged projected image provided by this West German photoscope is followed by a photoelectric head which controls the travel of the torch. In the January 1961 issue, the French Logatome cutting machine is described, which is based on a similar principle.

The thermit welding of rail joints on the Polish railways is described in the January and February issues. Pre-fabricated half-molds are used with four risers in each half. A graph shows that the aluminum addition must be lowered from 23.99% to 22.10% as the FeO content of the mill scale is raised from 13 to 14%.

The November 1960 issue describes experimental electroslag welding of boiler drums 2-in. thick. The contractions across the joint resulting from welding amounted to as much as 0.36 in.

A semiautomatic submerged arc welder for double lengthening oil and gas pipe in the field is described in the January 1961 issue. Also, in this issue is a metallographic study of welded 17% Cr Steel. Good results were obtained if the steel contained not over 0.06 C and about 0.35 Ti. The steel is welded with an austenitic electrode containing 18 Cr, 8 Ni and 6 Mn.

SWEDEN

The January 1961 issue *Svetsen* describes two method of erecting welded steel storage tanks. In one method the rings of plate are welded at ground level, then jacked upwards to allow another ring of plates to be welded at ground level. The second method is the Russian procedure of coiling the side plates of an entire tank in the shop and uncoiling it at the site. The coil may weigh 65 tons.

SWITZERLAND

The Swiss *Journal de la Soudure* for February 1961 reports tests in Germany on the fatigue strength of welded aluminum alloys: 5% Mg, and 1.3 Mg, 1.3 Si and also 4.5 Zn, 1.2 Mg in thicknesses from $^{5}/_{32}$ to $^{3}/_{4}$ in. A 5% Mg filler rod was used. The static tensile strength of welds was 50 to 72% of base metal. The fatigue strength of butt welds was 15,600 psi, compared with 24,000 to 27,000 psi for base metal. An aluminum alloy girder (Al–Mg–Si alloy) $4^{1}/_{2}$ ft high, 3 ft wide, 50 ft long was welded to serve as part of the lifting equipment for a ship transporting locomotives. The girder weighed $6^{1}/_{4}$ tons. The design stress for welded plate was 12,500 psi in bending. Multiple-pass inert-gas metal-arc welding was used at 380 amp and a travel speed of 16 to 24 imp.

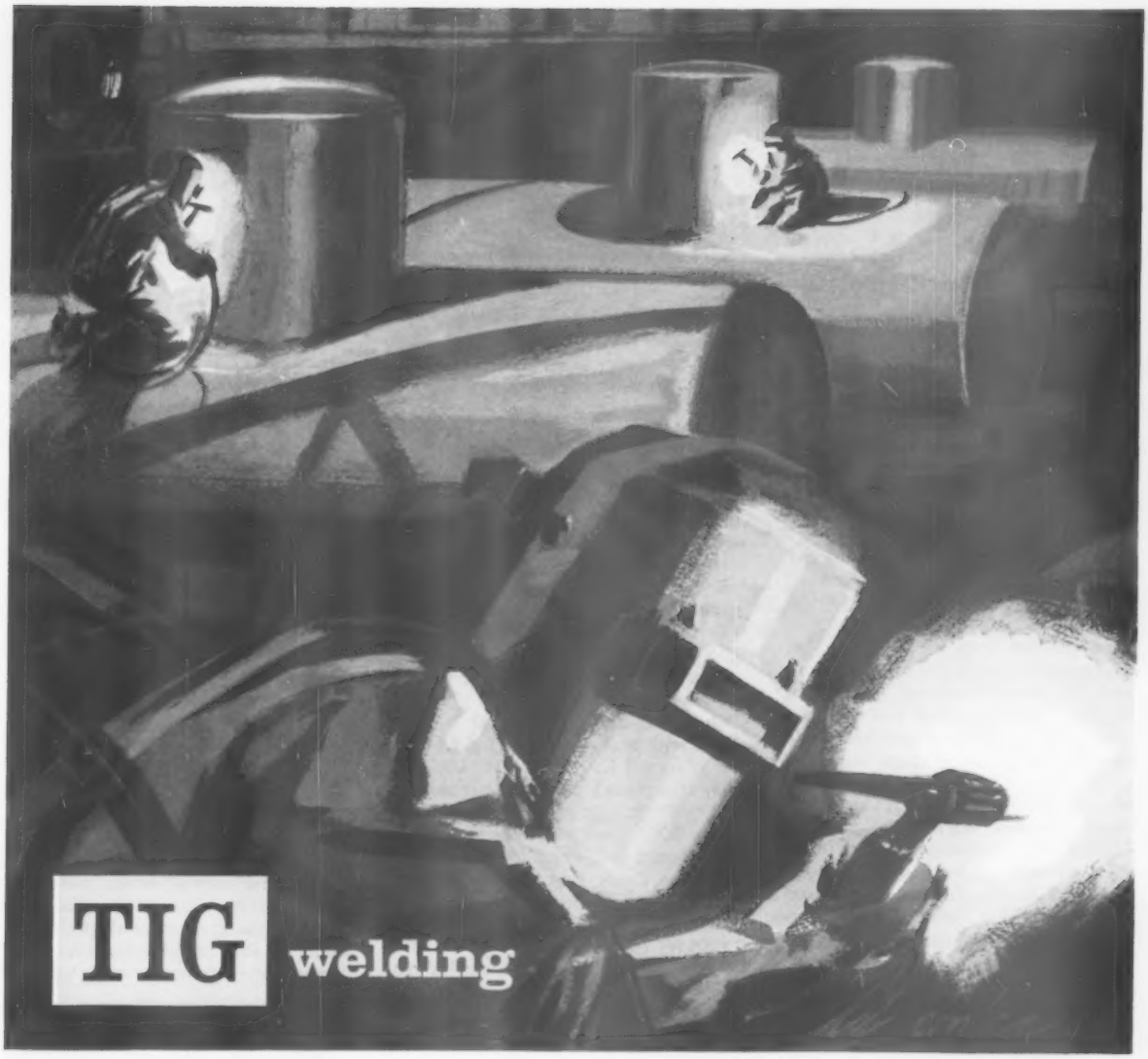
Oerlikon Schweissmitteilungen, Issue No. 39, 1960 contains a 14-page article on the economics of iron powder electrodes of the E6014 and E6024 types for welding horizontal and flat fillets: Particular attention was directed to root fusion and the efficiency of utilization of weld metal in approaching the ideal triangular bead cross section. The iron powder electrodes were fast and economical, but the author realizes their limitations.

This issue also contains a numerical example of the design of a welded column for a building.

USSR

Svarachnoe Proizvodsvto for Janu-

DR. GERARD E. CLAUSSEN is associated with Arcroda Corp. Sparrows Point, Md.



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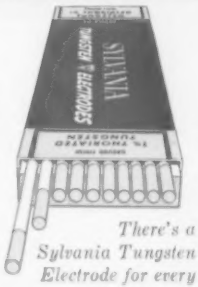

There's a Sylvania Tungsten Electrode for every welding need.

SYLVANIA

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ary 1961 issue contains the following:

• The manipulators and positioners manufactured by two Russian firms range in capacity from 1/2 to 22 tons. Head and tailstocks are available for assembling and welding the frames of agricultural machines, such as combines. Tilting hydraulic jacks are used for welding locomotive frames.

• Russian automatic heads for surfacing are of two types. The first type is for submerged arc surfacing and is conventional in design. Special equipment is built for special jobs, such as rebuilding locomotive drivers. The second type is for vibro-arc surfacing. Four designs are available: three for submerged arc, one for shielded gas surfacing. The term "vibro-arc" signifies that the electrode wire or the entire nozzle is given a transverse or circular oscillation at the rate of 47.5 or 100 cps. The feed of the electrode wire is slow: 13 to 52 ipm for diameters from 0.043 to 0.075 in. The speed of surfacing is 1 to 8 fpm, and the layer thickness is 0.008 to 5/32 in. The beads are narrow, the longitudinal feed of the electrode along a cylindrical surface being 1/16 to 3/16 in. The shallow penetration of the process makes it ideal for sheet metal 0.020 in. and thicker. Mild steel, alloy steel and stainless steel wires have been used successfully. Vibro-arc surfacing is used particularly for building up transmission shafts in tractors. Powder core wire is used without flux, gas, or vibration to build up steel mill rolls for rolling bars. The powder contains 4% ferromanganese, 20% ferrosilicon, 3% graphite, 7% aluminum, 10% ferrotitanium, 5% ferrovanadium, 5% ferrochromium, 14% ferrotungsten, 32% iron. Surfacing is done at 400 amp, 25–26 v, 26 ipm.

• Welding and cutting practice is described at a factory for diesel locomotives. An automatic electroslag welder is used to weld water jackets and pistons 3/4 to 1 5/8 in. thick. It is expected that the percentage of automatic welding in the factory will rise from 18.5% in 1959 to 54% in 1965.

• Surfacing operations at the Magnitogorsk Iron & Steel Combine include:

(*a*) Blast furnace bells surfaced with powder-core wire 0.14 in. diam by submerged-arc welding with high-alumina flux. The majority of the annealed cast steel bell is surfaced with five layers of metal containing 0.37–0.43 C, 0.6–0.7 Mn, 0.5–0.7 Si, 2.2–2.7 Cr, 7.5–9 W, 0.2–0.5 V. The deposit contains fine haircracks and has a Rockwell C hardness of 50–54. The remainder of the bell is surfaced with metal containing 3.6 Cr, 13 W or 2.6 C, 15 Cr, 2 W, 0.45 V. The completed bell is reheated to 820–930° F. It requires 270 hr to apply 3000 lb of surfacing material. The electrode is deposited at 400 to 650 amp, depending on its composition and on whether it is the first or subsequent layers. Travel speed is 14 to 38 ipm.

(*b*) Blooming mill shear knives are surfaced with the same electrode (7.5–9 W) used for the major part of the bell. Current is lowered to 240–380 amp.

(*c*) Hot rolls are surfaced with the 7.5–9 W composition in a positioner that permits tilting the roll for convenient surfacing of the roll grooves.

(*d*) Protective plating for blast furnace and sinter plants is surfaced with a six-electrode apparatus feeding mild steel wire and high MnO flux. The deposit is 4 in. wide.

(*e*) Crushing hammers are resurfaced with the 15 Cr wire used for the bells.

(*f*) Bronze parts are re-surfaced with high MnO flux and a bronze strip 0.032 x 2 in. containing 8–10 Al, 1.5–2 Mn.

• The diameter d of the covered electrode suitable for welding cavities in aluminum castings is said to be $d = \sqrt{a/b + H}$, where a and b are the maximum and minimum perpendicular dimensions of the cavity and H is the depth of the cavity.

• The literature on electron beam welding is reviewed, Russian equipment is described, and several industrial application to aluminum and stainless steel are discussed. The equipment required 22 to 25 kv.

• The April 1960 issue of this Russian magazine described arc welding in an atmosphere of steam or water vapor. The editors now print experience of seven groups of investigators who show that the process has encountered problems, such as slag inclusions, and that further development work is needed.

DENMARK

Manual arc welding, commonly employed by F. L. Smidth & Co., Copenhagen, on a 1-in. mild steel plate in a casing for a 3500 hp Symetro Drive for a grinding mill

WEST GERMANY

Schweissen und Schneiden for January 1961 contains the following articles:

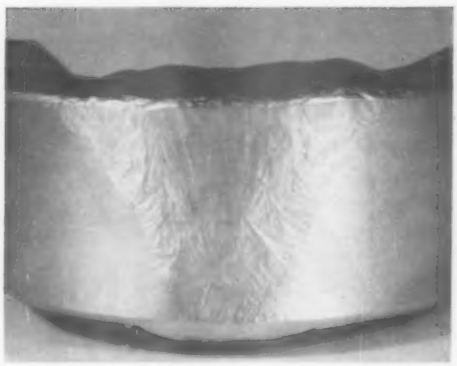
• In a review of developments in welding plastics it is asserted that filler wire should have a rough surface for best results. High-frequency welding is coming into favor for plastics having the necessary high dielectric loss angle.

• Small welding transformers for home use now contain low-cost condensers which, with easy-striking electrodes, prevent overloading of the home circuit.

• For gas welding, copper must be deoxidized. An excellent filler rod for gas welding copper contains 0.8% tin and some manganese. While brass requires an oxidizing flame, for bronze the flame must be absolutely neutral.

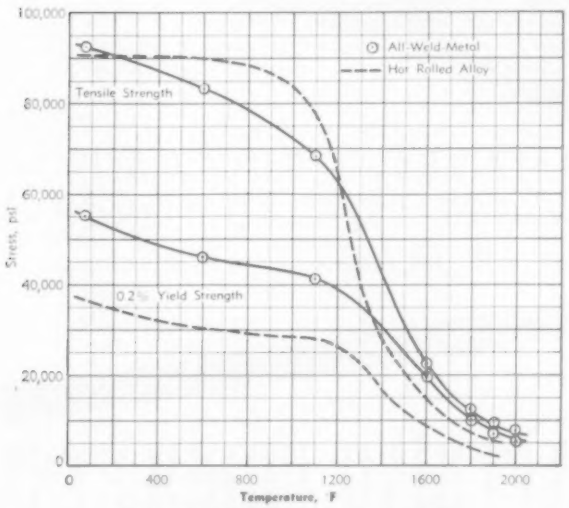
• Plastic adhesives for metals consist of methoxylin resin hardened with a polyamide and strengthened with metal powder.

Side-bend test specimen from butt joint between carbon steel (l.) and INCONEL alloy 600 (r.) welded with INCONEL Welding Electrode 182.

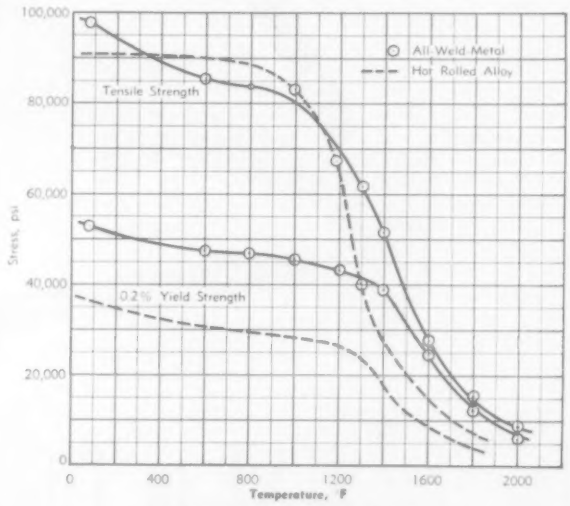


Side-bend test specimen of one inch thick butt joint between carbon steel (l.) and INCONEL alloy 600 (r.) welded with INCONEL Filler Metal 82.

Side-bend test specimen from butt joint of INCONEL alloy 600 (both sides) welded with INCONEL Welding Electrode 182.



INCONEL Welding Electrode 182
High Temperature Tensile Properties of All-Weld-Metal Deposits



INCONEL Filler Metal 82
High Temperature Tensile Properties of All-Weld-Metal Deposits

Two new welding products

to meet the demand for a high level of weld integrity in joining INCONEL alloy 600 to itself and to carbon or stainless steel.

INCONEL* Welding Electrode 182 and INCONEL Filler Metal 82 consistently produce welds of the highest quality when joining INCONEL alloy 600 (formerly designated as INCONEL alloy) to itself or to carbon or stainless steels.

INCONEL Welding Electrode 182 is a true all-position electrode in every respect — operability, slag removal, and weld quality.

The tolerance of the weld metal to dilution by iron makes these materials an excellent choice for welding INCONEL alloy 600 to carbon or stainless steels and for overlaying.

For complete information on these two new products, write for our descriptive bulletin and a reprint of the *Welding Journal* paper, "Welding of Nickel-Chromium-Iron Alloy for Nuclear-Power Stations."

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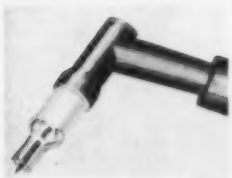

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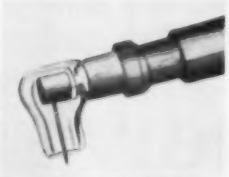

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Submerged-arc equipment is utilized to obtain weld metal deposition rates of 15 lb per hr and more in

Gas Metal-Arc Welding **Aluminum** with Large Diameter Fillers

BY JAMES A. LIPTAK

SYNOPSIS. Applying $^5/_{32}$, $^3/_{16}$ and $^7/_{32}$ in. diam fillers for gas metal-arc welding aluminum results in lower welding costs for plates thicker than $^3/_4$ in. Deposition rates of 15 lb per hour are readily attained as compared to 5 to 10 for conventional gas metal-arc welding, and can be extended to over 20 lb per hour on special applications.

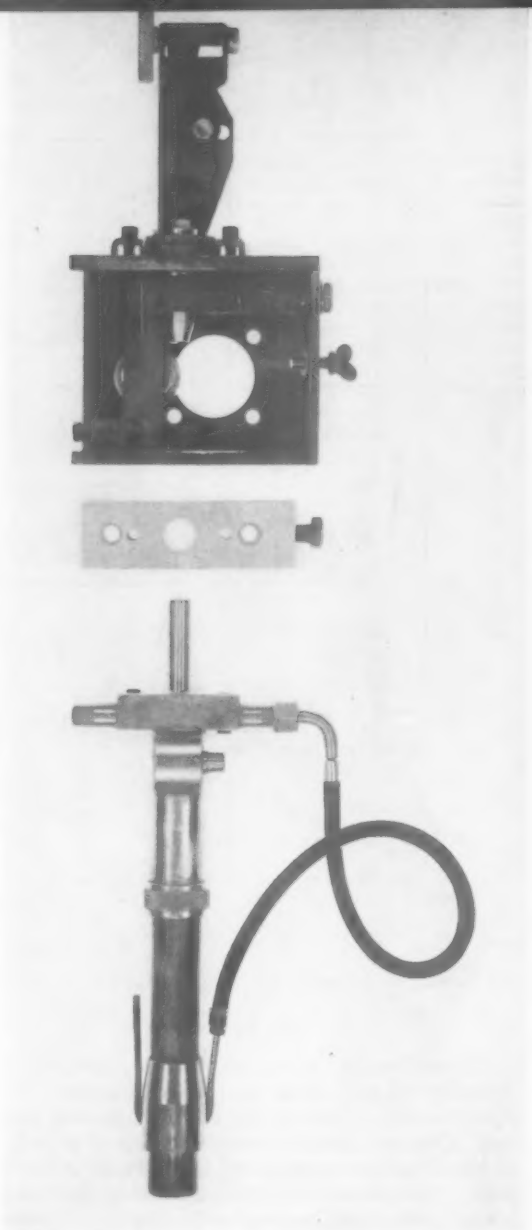
The new method operates at a current density ranging from 12,000 to 30,000 amp per sq inch, as compared with 50,000 to 100,000 for welding with small diameter wires. Because the current density is so low for the new process, standard gas metal-arc equipment is not satisfactory. Steel submerged-arc welding equipment, however, has the capacity for large diameter wires and a proper control system for welding at low current densities. Most submerged-arc equipment can be easily converted for gas metal-arc welding with large diameter fillers.

The effect of the welding parameters current, voltage, travel, preheat and inert gas were determined in the development of the large wire welding technique. Complete detailed welding procedures for a range of plate thicknesses from $^3/_4$ to 3 in. are given in Appendix A. Procedures and mechanical property data for plates welded with three wire sizes, each welded with four different inert gas atmospheres, on two types of commercial equipment are also included. These procedures were all qualified in accordance with the requirements of the ASME Boiler and Pressure Vessel Code Section IX.

Introduction

The expanding use of thick aluminum plate in such applications as armored military vehicles, aircraft carriers and large cryogenic applications has created a need for more economical procedures to weld aluminum plate in thicknesses greater than 1 in. A new, lower-cost method of welding heavy aluminum plate has been developed and investigated for plate thicknesses from $^3/_4$ up to 3 in. The method consists of gas metal-arc welding with $^5/_{32}$, $^3/_{16}$ and $^7/_{32}$-in. diam fillers. Deposition rates more than double those attained with present methods are achieved.

When multipass welding thick aluminum plates using a deep groove weld bevel, the weld metal deposition rate is the most important factor in determining welding efficiency. The weld metal deposition rate is, in turn, a function of the welding current. Thus, increasing the maximum usable welding currents results in lower welding costs. There is, however, a maximum practical current which can be used for a given filler wire size. Therefore, the efficiency and speed of aluminum welding has been limited, until now, by the $^1/_8$ in. maximum diam wire which has been available. If $^5/_{32}$-, $^3/_{16}$- and $^7/_{32}$-in. diam filler wires are used, higher deposition rates are possible through the use of higher currents.



Gas-metal-arc welding barrel adapted to submerged arc wire feeder. (Top unit has nylon bushings to prevent galling, and spacer block in center adapts gas metal-arc welding torch barrel to face plate of submerged-arc feeder. Block is rotated 90 deg to show drillings; bolts fastening plate to face plate must be flush and electrically insulate block from face plate. Welding cable is bolted to right of block using bolt shown)

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Paper to be presented at AWS National Fall Meeting in Dallas, Tex., during Sept. 25–28, 1961.

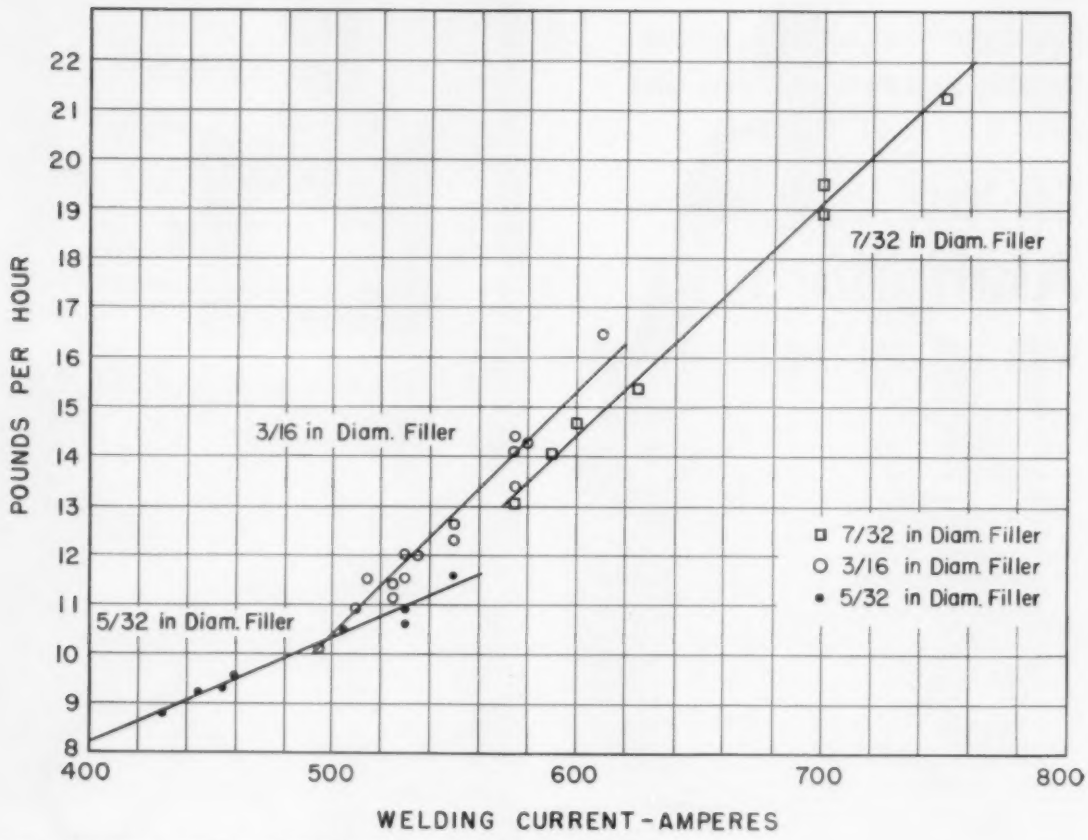


Fig. 1—Weld metal deposition rates for large diameter fillers argon shielding

Large-diameter aluminum fillers require heavier wire feeders and power supplies with higher capacities than those now in use for gas metal-arc welding. One very practical source for these wire feeders is submerged-arc welding equipment now in use on steel. Submerged-arc wire feeders are capable of straightening and feeding $^1/_4$-in. diam hard drawn steel wire and often have power supplies with three times the capacity of those used for gas metal-arc welding. The cost of converting submerged-arc equipment for gas metal-arc welding aluminum is very low, compared to the probable cost of new, specially designed equipment. Utilizing this existing equipment would also make the new process available to industry immediately.

The initial problem in the development of the large wire welding technique was that of suitable welding equipment. The solution of this problem was followed by the development of successful welding procedures for producing high quality weldments.

Characteristics of the New Process

Current Density

The most outstanding difference between welding with large diameter fillers and conventional size fillers is in the current density and the resultant change in metal transfer across the arc. The new welding process operates in a lower current density range of 12,000 to 30,000 amp. per square in.,

Fig. 2—Submerged-arc contact tip adapted to gas metal-arc barrel with two oxygen standard coupling nuts silver brazed back-to-back

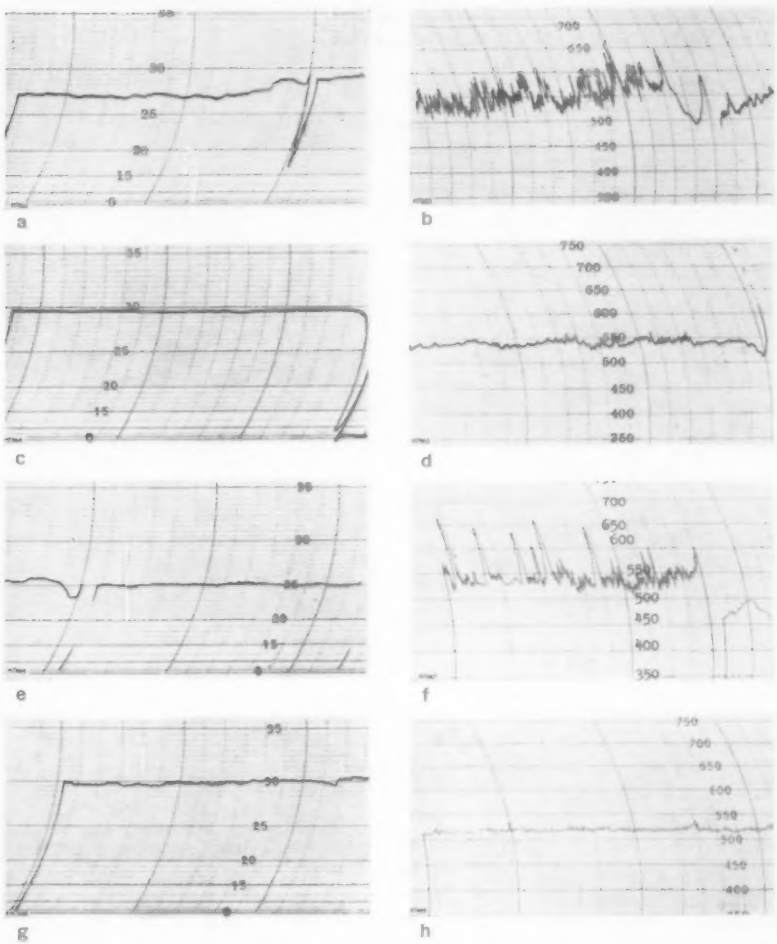


Fig. 3—Typical voltmeter and ammeter traces for various equipment combinations—14,600 amp per sq in. current density. (Voltmeter traces on left and ammeter traces on right. Top pair—constant wire feed and constant potential; second pair—constant wire feed and constant energy; third pair—variable wire feed and constant potential; bottom pair — variable wire feed and constant energy)

while conventional welding with small diameter fillers generally operates from 50,000 to 100,000 amp per square in. Due to this lower current density, the metal transfer across the arc is globular instead of a fine spray as with small diameter fillers.

Deposition Rates

The weld metal deposition rates for $^5/_{32}$", $^3/_{16}$" and $^4/_{32}$-in. diam fillers are given in Fig. 1. Deposition rates of from 10 to 15 lb per hr are readily achieved and, on special applications, can be extended to over 20 lb per hr. Conventional gas metal-arc deposition rates for aluminum range from 5 to 10 lb per hr.

Penetration

To avoid confusion between the words penetration and fusion, for this paper the word penetration refers to the depth of the melted weld bead. The word fusion refers to the side walls of the welding groove.

The depth of weld bead penetration is generally considered to be a function of welding current and travel speed. Higher currents and slower travel speeds increase penetration. In developing the large wire technique, two other variables were found to have a significant effect on penetration. Penetration is increased considerably with higher voltages. Penetration is also increased by adding helium to the argon gas shielding.

Welding Equipment

Converting Submerged-arc Equipment for Gas Metal-arc Welding with Large Diameter Fillers

Nearly all steel submerged-arc welding is done in the same low current density range that is required for welding aluminum with large diameter fillers. Submerged-arc equipment, which uses the variable wire feed control system, is best suited for gas metal-arc welding aluminum with large diameter fillers. To convert this equipment requires only replacement of the flux and contact tip system with a water-cooled, inert gas welding barrel of sufficient capacity. Such welding barrels are available and can be easily adapted as shown in the lead photograph and Fig. 2. The test plates listed in Table 1 were welded on two different types of commercial equipment converted in this manner.

Table 1—Detailed Test Results: Gas Metal-arc Butt Welds Made with Large Filler Wires

Materials	Plate thickness, in.	Filler diameter, in.	Technique	Inert gas	No. of plates welded	Average transverse properties: Ultimate tensile strength, psi	Yield strength psi	Elongation in 2 in., %	No. of specimens used to determine averages: Mechanical properties	2T side bends
5083	1 3/16	5/32	2 pass	Argon	10	41,350	19,600	18.7	20	40
plate;		3/16	2 pass	Argon	10	41,500	20,400	17.3	20	40
5183		7/32	2 pass	Argon	10	41,350	18,900	18.9	20	40
filler										
	1 3/16	5/32	2 pass	10% He – 90% A	2	42,100	19,600	21.8	8	8
		3/16	2 pass	10% He – 90% A	2	41,400	19,900	18.0	8	8
		7/32	2 pass	10% He – 90% A	1	40,500	22,600	13.0	4	4
	1 3/16	5/32	2 pass	25% He – 75% A	2	41,400	18,900	21.8	8	8
		3/16	2 pass	25% He – 75% A	2	41,600	19,300	22.7	8	8
	1 3/16	5/32	2 pass	75% He – 25% A	10	41,300	19,400	22.1	20	40
		3/16	2 pass	75% He – 25% A	10	42,100	18,600	20.4	20	40
		7/32	2 pass	75% He – 25% A	5	41,500	18,800	24.1	20	20
	3	5/32	Multipass	Argon	1	41,200	21,800	19.4	8	8
		3/16	Multipass	Argon	1	40,800	19,600	21.7	8	8
		7/32	Multipass	Argon	1	40,900	19,500	21.2	8	8
	3	5/32	Multipass	10% He – 90% A	1	41,750	21,700	20.6	8	8
		3/16	Multipass	10% He – 90% A	1	40,500	19,400	21.1	8	8
		7/32	Multipass	10% He – 90% A	1	40,800	19,300	22.1	8	8
	3	5/32	Multipass	25% He – 75% A	1	40,300	19,900	19.9	6	8
		3/16	Multipass	25% He – 75% A	1	40,800	19,600	21.2	8	8
		7/32	Multipass	25% He – 75% A	1	40,600	19,700	22.2	8	8
	3	5/32	Multipass	75% He – 25% A	2	41,700	21,200	18.3	16	16
		3/16	Multipass	75% He – 25% A	3	41,400	21,500	21.4	24	24
		7/32	Multipass	75% He – 25% A	2	41,400	21,200	21.0	16	16
5456 plate;	1 3/16	5/32	2 pass	Argon	3	42,300	20,700	16.1	12	12
5556		3/16	2 pass	Argon	3	42,800	21,000	17.8	12	12
filler		7/32	2 pass	Argon	3	42,300	19,800	17.5	12	12

Materials	Plate thickness, in.	Filler diameter, in.	Technique	Inert gas	No. of plates welded	Average transverse properties: Ultimate tensile strength, psi	Yield strength psi	Elongation in 2 in., %	No. of specimens used to determine averages: Mechanical properties	2T side bends
	1 3/16	5/32	2 pass	10% He – 90% A	2	42,100	20,900	16.0	8	8
		3/16	2 pass	10% He – 90% A	2	43,000	20,700	20.2	8	8
		7/32	2 pass	10% He – 90% A	2	43,000	20,700	19.1	8	8
	1 3/16	5/32	2 pass	25% He – 75% A	2	42,700	20,800	17.8	8	8
		3/16	2 pass	25% He – 75% A	2	43,100	20,800	20.1	8	8
		7/32	2 pass	25% He – 75% A	2	42,800	20,700	20.2	8	8
	1 3/16	5/32	2 pass	75% He – 25% A	2	42,700	20,600	20.1	12	12
		3/16	2 pass	75% He – 25% A	3	42,500	19,900	22.5	10	12
		7/32	2 pass	75% He – 25% A	3	42,400	19,900	21.4	12	12
	3	5/32	Multipass	Argon	1	43,000	21,900	20.0	8	8
		5/16	Multipass	Argon	1	42,400	20,700	20.9	4	8
		7/32	Multipass	Argon	1	42,000	21,200	21.0	6	8
	3	5/32	Multipass	10% He – 90% A	1	42,900	22,000	20.0	8	8
		5/16	Multipass	10% He – 90% A	1	42,400	21,200	22.8	8	8
		7/32	Multipass	10% He – 90% A	1	42,300	20,800	21.6	8	8
	3	5/32	Multipass	25% He – 75% A	1	43,100	21,400	21.0	8	8
		5/16	Multipass	25% He – 75% A	1	42,300	20,800	21.2	8	8
		7/32	Multipass	25% He – 75% A	1	42,300	21,000	22.7	6	8
	3	7/32	Multipass	75% He – 25% A	1	42,400	20,200	22.3	8	8
EC plate, 1100 filler	1 1/4	5/32	2 pass	Argon	2	10,700	4,800	67.3	8	8
		3/16	2 pass	Argon	2	10,800	4,500	61.5	8	8
		7/32	2 pass	Argon	2	10,400	4,350	62.5	8	8
	1 1/4	5/32	2 pass	75% He – 25% A	1	10,750	4,550	69.0	4	4
		3/16	2 pass	75% He – 25% A	1	11,000	4,450	61.5	4	4
		7/32	2 pass	75% He – 25% A	1	10,600	4,400	66.7	4	4

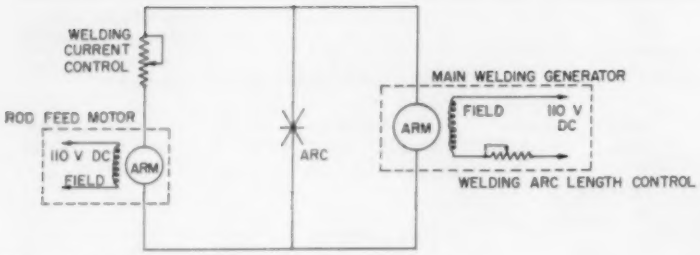


Fig. 4—Simplified schematic for typical submerged arc wire feeder using variable feed rate

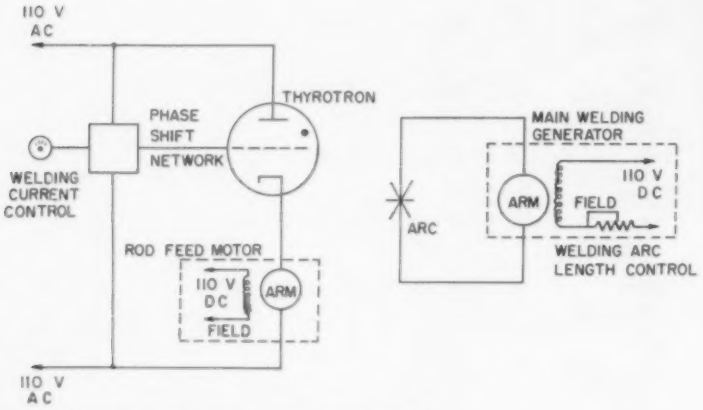


Fig. 5—Simplified schematic for typical gas metal-arc wire feeder using constant wire feed

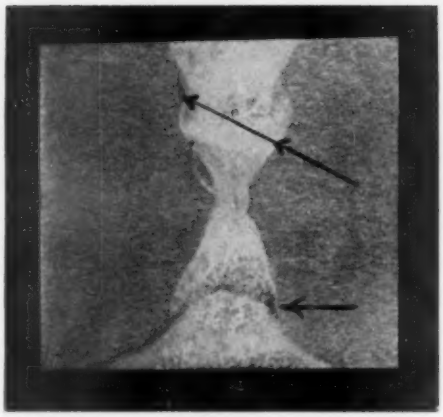


Fig. 6—Typical lack of fusion at sides of welding groove due to narrow groove and long arc. × 1. (5083 plate—5183 filler)

Selection of Suitable Equipment Combinations

The automatic welding equipment commonly used both for submerged-arc welding steel and gas metal-arc welding aluminum can be broken down into two basic components: wire feeder and power supply. These, in turn, can be further divided into:

1. Wire feeder
   (*a*) Constant feed
   (*b*) Variable feed
2. Power supply
   (*a*) Constant voltage
   (*b*) Constant energy

Intermixing these basic components results in four possible combinations. Each of the four was considered for gas metal-arc welding aluminum with large diameter fillers. Typical voltmeter and ammeter traces for each are shown in Fig. 3. The travel speed in all cases was 10 ipm and one major division on the chart represents approximately $3^1/_3$ in. of weld. It would appear that the variable wire feed with the constant energy power supply produced the most stable welding conditions with this new welding process. The other equipment combinations apparently do not have sufficient ability to maintain stable welding.

Any welding control system must be capable of compensating for two basic variables—first, variations in the torque load on the wire feed motor and, second, instantaneous changes in the burn-off rate. Figures 4 and 5 are block diagrams of two basic control systems—one for a submerged-arc steel welding unit and the other for a conventional gas metal-arc unit for welding aluminum.

In the constant wire feed gas metal-arc welding control, the rod feed motors are usually low horsepower, high speed motors which develop torque through gear reduction. Torque load variations on the motor are compensated for by the electronic control device. Instantaneous changes in the wire burn-off rate are compensated for by the self-regulating effect of the power supply.

In the variable wire feed systems, the rod feed motors are generally higher horsepower shunt wound d-c motors. Variations in the torque load are compensated for by the inherently low speed regulation of this type of motor. Burn-off rate changes are compensated for by the self-regulating effect of the power supply. However, in the variable wire feed system, the rod feed motor armature is connected across the welding arc; therefore, changes in arc voltage are reflected as power changes to the rod feed motor and tend to adjust its speed to restore proper arc length. The variable wire feed system has three control features, while the constant feed system has only two. As shown by the meter traces in Fig. 3, this additional control is necessary for stable

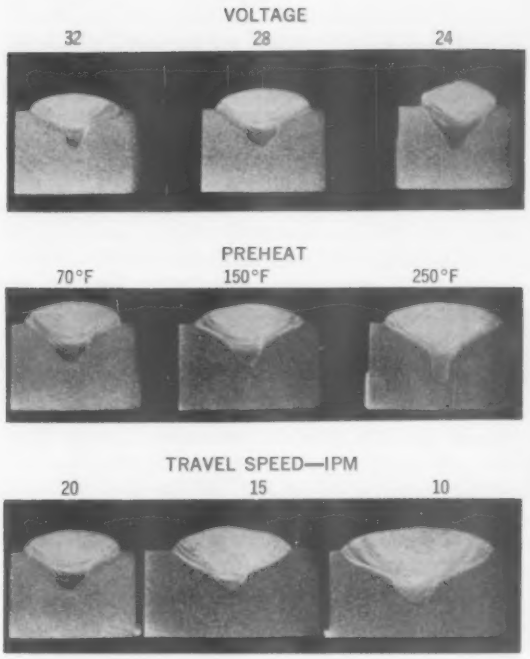


Fig. 7—Effect of various welding procedures on weld bead shape (500 amp., 20 ipm, argon)

gas metal-arc welding aluminum with large diameter fillers.

The current density of the welding operation governs the type of control system necessary for stable welding. The higher the current density, the more stable the welding operation and, therefore, a constant wire feed as used in conventional welding is adequate. Welding operations at a current density in excess of 40,000 to 50,000 amp psi were found to be sufficiently self-regulating to allow the use of a constant feed control. Conversely, an unstable low current density welding process requires the additional control of the variable wire feed system. Since gas metal-arc welding aluminum with large diameter fillers is carried out in a current density range of about 12,000 to 30,000 amp per sq in., the variable wire feed control system is necessary.

Development of Welding Technique

Effect of Arc Length

The initial welding procedures used to make butt welds with large diameter fillers were carried out using the normal spray type arc. The result was a lack of fusion to the side walls shown in Fig. 6. Examination of many of these cross sections showed that the difficulty was caused by an undesirable weld bead shape, i.e., one having a deep papillary penetration pattern.

Using argon shielding, several bead-on plate welds

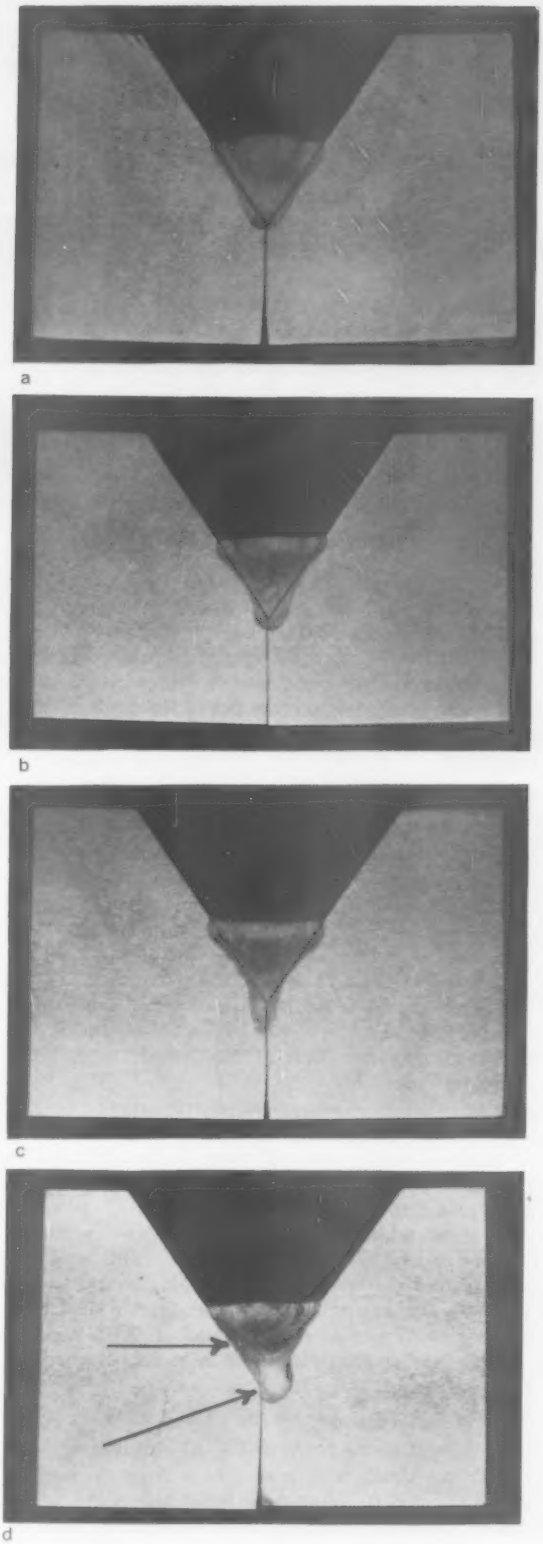


Fig. 8—Effect of arc voltage on bead shape of first pass weld in a vee groove—500 amp, 10 ipm and $^{5}/_{32}$-in. diam filler. (Beginning at top, welds made as follows: a—22.5 v, b—24 v, c—26 v and d—26 v with 3-deg tilt on head. Arrows indicate lack of fusion)

were made to determine the effect of various welding procedures on the weld bead shape. Figure 7 shows transverse macrosections of a series of bead-on plate welds. The low voltage short arc effectively minimizes the papillary. Reducing the travel speed also minimizes the papillary, but to a lesser degree, while increasing the preheat reverses the trend.

Figure 8 (a, b and c) shows the effect of voltage or arc length on the bead shape of the first pass in a deep groove weld. The original location of the weld groove side walls has been scribed over the bead to indicate penetration. It will be noted that the long arcs, although having a deeper penetration at the root, almost miss 100% fusion to the side walls of the welding groove. The shorter arc gives less penetration at the root but more fusion at the side walls. The lack of fusion shown in Fig. 8(d) is typical of the danger in using a conventional spray arc. This particular defect was caused by deliberately tilting the head only 3 deg from the vertical position. However, the same condition would result if the head wandered slightly off the centerline of the seam, if improper tension at the wire straightener caused the wire to come out of the contact tube in a curve, or if some form of arc blow was encountered.

Techniques for Measuring Arc Length

Since arc length is a critical variable in the new welding technique, a method for measuring or judging arc length is necessary. The most common measure of arc length is arc voltage. Higher voltages indicate longer arcs. All arc voltages reported in Appendix A are true arc voltages measured from the contact tube to the test plate. There is a wide variation in the connection of voltmeters on commercial equipment. Because of these differences and variations in the length of welding cables, ground leads and water cooled cables, the true arc voltage does not necessarily appear on the meters. In practice, the voltages observed on commercial equipment will have to be corrected to compensate for these various IR drops before referring to Appendix A.

If these additional voltage drops are unknown, the arc can be judged by its sound. The short arc is characterized by its sharp popping sound as opposed to the hissing sound of the conventional long arc. The arc should be shortened until the characteristic hissing disappears and is replaced with the popping sound.

Effect of Travel Speed

Lack of fusion (shown in Fig. 6) also occurs when the travel speed is increased to a point where the arc is allowed to impinge on solid base plate. The travel speed should always be sufficiently slow to allow the arc to impinge on the molten puddle.

Effect of Welding Groove

The shape of the welding groove also affects the tendency toward lack of fusion to the side walls. In general, deep narrow U grooves are more susceptible to lack of fusion defects than are Vee grooves. The U type grooves should not be used with argon shielding. They can be applied on materials over 2 in. thick, but the additional heat input of a 75% helium–25% argon gas mixture is necessary to insure proper fusion to the side walls of the welding groove.

Weld Bead Penetration and Appearance

Root penetration is definitely decreased with the short arc, thereby requiring thinner lands on the welding grooves and more accurate fit-up in order to insure 100% penetration when using the two pass welding technique. The weld bead resulting from the short arc technique and argon shielding takes on a rippled appearance similar to that obtained with E-6010 steel electrodes. Both the penetration and appearance can be improved by merely lengthening the arc and operating it in the spray transfer range. The use of long arc increases the heat input and smooths out the weld bead. However, as previously shown, long arcs are undesirable. Therefore, in view of these conflicting arc properties, a method of increasing the heat input for a short arc had to be found in order to maintain proper bead shape, increase penetration and improve appearance.

Helium Additions to the Inert Gas

Additions of helium to the inert gas shielding with its higher ionization potential as compared to argon results in a higher arc voltage for a given arc length and will thereby increase the heat input from a short arc. Again, bead-on plate welds were used to show the effect of increasing amounts of helium added to the argon inert gas shielding. The transverse macrosections shown in Fig. 9 indicate that with increasing helium content the penetration increases and that the formation of the papillary at the bottom of the weld bead is minimized. In applications where appearance is of prime importance, the use of a 10% helium – 90% argon mixture is recommended. Where increased penetration is required, a 25% helium – 75% argon mixture can be used. As stated earlier, decreasing the formation of the papillary at the bottom of the weld bead has the advantage of making the process less susceptible to the normal operating irregularities. In welds where severe misalignment is likely to occur, a 75% helium – 25% argon shielding is recommended. Although the beads shown in Fig. 10 are badly misaligned, 100% fusion was still attained.

Welding Procedures

In Appendix A are given the complete, detailed welding procedures for both butt weld and fillet welds for a range of plate thicknesses from $^{3}/_{4}$ to 3 in. Procedures are given for both single and double bevel welding grooves. In general, the two-pass technique is used for plates up to $1^{1}/_{2}$ in. thick, while the multipass technique is used for plates over $1^{1}/_{2}$ in. thick. *Every welding procedure in Appendix A has been qualified to meet the requirements of the ASME Boiler and Pressure Vessel Code Section IX.* Although the procedures were developed with 5083

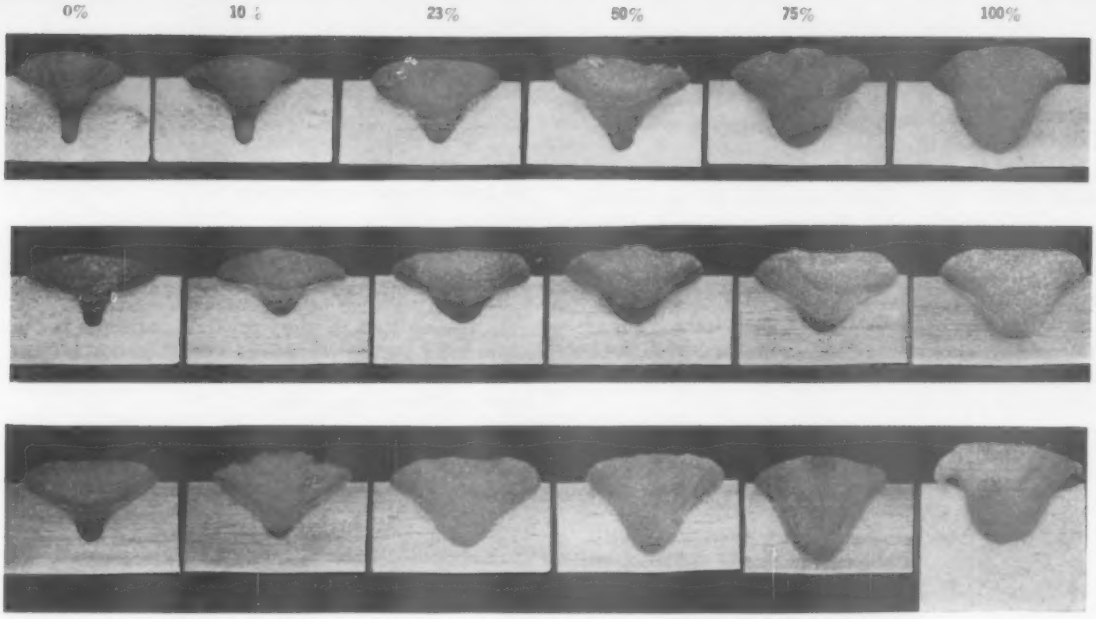


Fig. 9—Effect on bead shape of increasing helium additions to the argon shielding. (Welds made with filler wire as follows: top—$^{5}/_{32}$ in. diam; middle—$^{3}/_{15}$ in. diam; bottom—$^{7}/_{32}$ in. diam. Percentages indicate helium content; balance is argon)

plate using 5183 filler, they have been shown to be applicable to welding 5456 plate with 5556 filler and EC plate with 1100 filler.

The use of the short arc, proper travel speed and correct weld groove is essential to successful gas metal-arc welding of aluminum with large diameter fillers. Butt welds made using the proper technique will have mechanical properties more than sufficient to meet the requirements of the ASME Boiler and Pressure Vessel Code Section IX.

Aluminum Alloy Weldments

The mechanical properties of 5083, 5456 and EC plate weldments made by the new process are listed in Table 1. Values are listed for weldments made using all three large diameter wire sizes each with four different inert gas atmospheres. Data for multipass and two pass welding techniques are also included. In all, 102 plates were welded and results of 502 tensile and 502 bend tests from these weldments are summarized in Table 2.

Ultimate tensile strength values are approximately 1000 to 1500 psi less than those commonly obtained for weldments made with conventional gas metal-arc welding. This is to be expected because of the higher heat inputs and the resulting slower weld metal cooling rates. However, in no case did the transverse tensile strength drop below the guaranteed minimum properties specified for the "O" temper of the material being welded.

Along with this slight drop in tensile strength, there was the expected increase in the transverse elongation. Higher heat inputs resulted in greater annealing in the heat-affected zone, allowing this zone to elongate more under test. This is further illustrated by the fact that all 5456 plates welded with 5556 filler were able to pass the standard ASME 2T bend test. This material is now allowed a 3½T bend test under the rules of the ASME Boiler and Pressure Vessel Code Section IX.

Since the tensile strengths of the weldments do not drop below the guaranteed properties for the "O" temper of the material involved, aluminum pressure vessel designs will not be penalized and the increased ductility should be favorably viewed by many designers.

Table 2—Summary of Mechanical Properties for Weldments Made with Large Diameter Fillers and Conventional $^{1}/_{16}$-In. Diam Fillers

Weldment	Technique	Ultimate tensile strength psi	Yield strength, psi	Transverse % elongation in 2 in.	No. of side bends
5083-5183	2 Pass	41,500	19,400	20	156
5083-5183	Multi-pass	41,100	20,600	21	126
EC-1100	2 Pass	10,700	4,500	64	36
5456-5556	2 Pass	42,600	20,500	19	115
5456-5556	Multi-pass	42,500	21,100	21	80
5083-5183	Conventional	43,800	21,800	16	40

Fig. 10—$1^{3}/_{16}$-in. 5083—H115 weldment showing effect of filler wire misalignment ($^{3}/_{16}$-in. diam 5.83 filler wire; 75% helium 25% argon)

Conclusions

1. High quality gas metal-arc weldments which meet ASME code requirements can be made using 5/32", 3/16" and 7/32"-in. diameter aluminum fillers. Plates up to 1 1/2 in. thick can be two pass welded and plates from 1 1/2 to 3 in. can be multipass welded.

2. Steel submerged-arc equipment having a variable wire feed control system is suitable for gas metal-arc welding aluminum with large diameter fillers and can be readily converted at low cost.

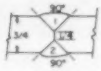
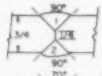
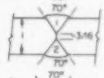
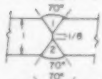
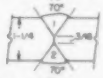
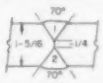
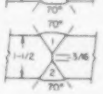
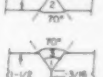
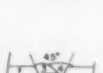
3. Weld metal deposition rates of 15 lb per hr are readily attained and can be extended to over 20 lb per hr on special applications.

4. The use of a short arc and proper travel speed is essential to the successful application of large diameter aluminum fillers.

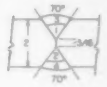
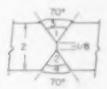
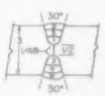
5. The addition of small amounts of helium to the argon inert gas shielding is beneficial to the welding operation with respect to increased penetration and improved bead appearance.

APPENDIX A

Typical Welding Procedures for Gas Metal-Arc Welding Aluminum with Large Diameter Fillers

Plate thickness, in.	Filler diameter, in.	Inert gas[a]	Current, amps.	Volts[b]	Travel, ipm	Pass location	Joint design
3/4	5/32	A-100	450	28	16	1st side	
	5/32	A-100	500	28	16	2nd side	
3/4	3/16	A-100	450	32	15	1st side	
	3/16	A-100	500	32	15	2nd side	
1	5/32	A-100	450	28	10	1st side	
	5/32	A-100	500	28	10	2nd side	
1	3/16	A-100	500	26.5	12	1st side	
	3/16	A-100	500	26.5	12	2nd side	
1 1/4	3/16	A-100	550	26.5	10	1st side	
	3/16	A-100	550	26.5	10	2nd side	
1 1/4	5/32	A-100	500	25	10	1st side	
	5/32	A-100	500	27	10	1st side	
	5/32	A-100	500	26	12	Back chip	
1 5/16	3/16	A-100	550	29	8	1st side	
	3/16	A-100	575	29	8	2nd side	
1 1/2	7/32	A-100	650	27	8	1st side	
	7/32	A-100	675	27.5	8	2nd side	
1 1/2	5/16	A-100	550	26	10	1st side	
	5/16	A-100	575	27	10	2nd side	
	5/16	A-100	600	29	10	1st side	
	5/16	A-100	600	29	10	2nd side	
1 3/4	5/16	A-100	600	28	10	1st side	
	5/16	A-100	600	28	10	2nd side	
	5/16	A-100	500	27	14	Multiple pass technique	
	5/16	A-100	500	27	14		
	5/16	A-100	500	27	14		
	5/16	A-100	500	27	14		
1 3/4	7/32	A-100	650	26	10	1st side	
	7/32	A-100	650	26	10	2nd side	
	7/32	A-100	600	27	10	1st side	
	7/32	A-100	600	27	10	2nd side	
1 3/4	5/16	A-100	600	28	10	1st side	
	5/16	A-100	600	28	10	1st side	
	5/16	A-100	550	30	14	1st side	
	5/16	A-100	550	30	14	1st side	
	5/16	A-100	550	30	10	Back chip	

(*Continued on p. 927*)

Plate thickness, in.	Filler diameter, in.	Inert gas[a]	Current, amps.	Volts[b]	Travel, ipm	Pass location	Joint design
2	3/16	H-120	550	31	10	1st side	
	3/16	H-120	550	33	10	2nd side	
	3/16	H-120	550	32	10	1st side	
	3/16	H-120	550	33	10	2nd side	
2	7/32	A-100	600	26	10	1st side	
	7/32	A-100	600	28	10	2nd side	
	7/32	A-100	600	30	10	1st side	
	7/32	A-100	600	30	10	2nd side	
2	3/16	A-100	600	28	10	1st pass	
	3/16	A-100	600	28	10	2nd pass	
	3/16	A-100	500	26	14	(Next 5) multipass	
	3/16	A-100	550	28	10	Back chip	
3	3/16	25% He	600	25	9	1, 2	
	3/16	25% He	500	23	11	3, 4	
	3/16	25% He	625	26	9	5, 6	
	3/16	25% He	600	27	9	7–12	
3	7/32	25% He	650	25	9	1, 2	
	7/32	25% He	500	23	10	3, 4	
	7/32	25% He	650	26	9	5, 6	
	7/32	25% He	625	27	9	7–10	
3	7/32	H-120	650	29	10	1, 2	
	7/32	H-120	650	31	10	3–6	

Fillet size, in.	Filler diameter, in.	Current, amps.	Volts	Travel, ipm	Inert gas[a]	Pass no.	
1/2	5/32	525	22	12	A-100	Single pass	
5/8	5/32	525	22	10	A-100	Single pass	
3/4	5/32	600	25	10	A-100	Single pass	
1	5/32	600	25	12	A-100	1st pass	
	5/32	555	24	10	A-100	2, 3	
1 1/4	5/32	600	25	10	A-100	1st pass	
	5/32	600	25	10	A-100	2, 3	
1/2	3/16	550	25	12	A-100	Single pass	
3/4	3/16	625	27	8	A-100	Single pass	
1	3/16	625	27	8	A-100	1st pass	
	3/16	550	28	12	A-100	2, 3	
1 1/4	3/16	625	27	8	A-100	1st pass	
	3/16	600	28	10	A-100	2, 3	
5/8	7/32	625	22	8	A-100	Single pass	
1	7/32	675	23	6	A-100	Single pass	
1 1/4	7/32	625	22	8	A-100	1st pass	
	7/32	625	22	10	A-100	2, 3	
1 1/2	7/32	650	23	6	A-100	1st pass	
	7/32	650	23	10	A-100	2–4	

[a] A-100 indicates pure argon at 100 cfh flow. H-120 indicates 75% helium–25% argon at 120 cfh flow; 25% He indicates 25% helium–75% argon at 100 cfh flow.

[b] Voltages are measured from contact tube to test plate. Somewhat higher readings will result if drops in welding and ground leads are included.

Stern frame of S.S. Del Rio following fabrication by thermit welding from seven separate castings

"Cast-welding" is shown to have numerous advantages in

Use of Welding to Produce **Intricate Shapes**

Prepared by the Staff of the Steel Founders' Society of America

SYNOPSIS. Cast-welding is solving many difficult problems in the production of intricate shapes. When a complicated casting is being designed, it would be well for design engineers at the very outset to think of the finished piece as a composite casting of simple components. Such components being simpler can thus be produced more quickly, inexpensively and conveniently than as a part of a single casting. These components can then be welded together to make up a solid, one-piece integrated assembly. Sizes and configurations of cast weldments are limited only by one's imagination.

This method of producing finished castings of unlimited sizes and shapes is preferred when space, time and costs are foremost factors. Thus the Steel Founders' Society of America suggests a review and consideration of this production method. Machine operations can frequently be started and sometimes even completed before the assembly of the components. Total weight of some proposed castings can often be reduced by welding on a lightweight component instead of using the heavier segment design of a one-pour casting. And yet, with these and many other advantages, the finished, assembled casting is just as permanently strong and neat appearing as a casting which has been poured at one time. Modern welding practices make all of this possible.

Cast-Welding—What Is It?

Cast-welding is the joining of one casting to another by welding. Users of this method of fabrication are solving production problems of intricate shapes. Components with varied material specifications may be used by incorporating steel castings, wrought steel forgings, steel plates, steel bars or steel tubes as one or more components in the completed one-piece integrated unit. This whole concept has attracted much interest in the steel foundry industry over the past several years.

Usefulness Unlimited

The shapes of steel castings can be so intricate that a one-piece casting may be much too costly in both

time and money. Furthermore, smaller and less complex castings have inherently improved soundness and higher quality than larger more complex shapes that are expensive to riser and feed. The end product is quite likely, therefore, to be of better quality than could be obtained in one piece castings. Thus cast-welding can be the answer, if hot spots and high residual internal stresses cannot be eliminated.

The reader may recall situations which have arisen where it was impractical to produce a steel casting in one piece because of its design, cost or weight. It is in situations such as this that weld-casting has many benefits. Flexibility of design, additional strength, dollar savings in machining and casting costs, weight reduction, and location of the weld away from high stress zones are some advantages to name a few. Improved methods of welding make all of this possible. There is virtually no limit to the size and configuration of cast weldments, whereas there is a practical limit as to what can be produced in a single casting. The same welding procedures and joint design are used for welding castings as used for wrought materials of the same chemical type and thickness.

One of the most simple, yet practical applications of cast-welding is the always present problem of the appendage. The appendage, whether it has been cast or produced by some other means, can be welded into place inexpensively and conveniently to complete the desired design. Shapes, incorporating self-locating devices for accurate assembly, are frequently used in making up the integrated assembly of an intricate design. Cast-welding also suggests an inexpensive way to produce right and left-hand shapes.

A Few Applications

Cast-weld designs are used in many applications, including high-pressure and high-temperature service and nuclear power applications. The illustrations which follow, point out a few of the many possibilities of cast-welding. Furthermore, these illustrations may suggest many other opportunities where cast-welding can be used to advantage in particular operations.

Welding Light to Heavy Sections

As shown in Fig. 1, a lightweight, split steam chest was welded to a heavier, high-pressure, outer, upper shell with the automatic submerged-arc welding process, using alloy steel wire. The inlet flanges were cast separately and then welded by the manual submerged-arc process to the steam-chest. The appendage (bracket) in the foreground of Fig. 1—a means of supporting a hydraulic operating machine—was also manually welded to the upper shell by the submerged-arc process, effecting a savings in pattern cost.

Design Freedom

Intricate shapes can easily be welded together to form a particular design. This is illustrated in Fig. 2 where a high-pressure, outer, lower shell was welded to a steam inlet elbow and reheat steam inlet elbow. Both of these elbows were welded on manually with submerged-arc welding.

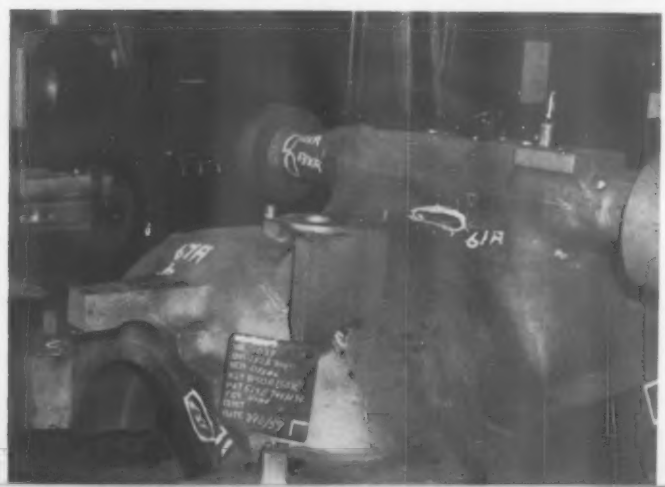
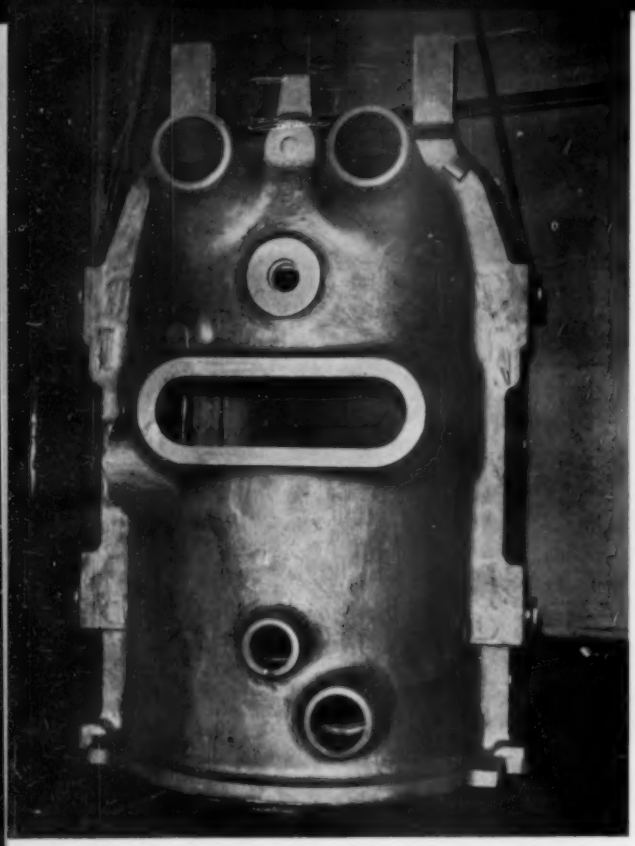


Fig. 1—High pressure outer upper shell showing cast-weld construction. The split steam chest was welded to the shell, and the inlet flanges were cast separately and welded to the steam chest. The bracket in the foreground is fabricated to the shell and supports the hydraulic operating mechanisms

Fig. 2—High pressure outer lower shell with welded-on steam inlet elbow and reheat steam inlet elbow



A. High-pressure outer shell

B. Steam chest

Fig. 3—High-pressure outer shell and full steam chest prior to assembly by cast welding

Fig. 4—Intercept valve casing with stub pipes welded to the outlets and a flanged elbow welded to the cleanout opening between the outlet pipes

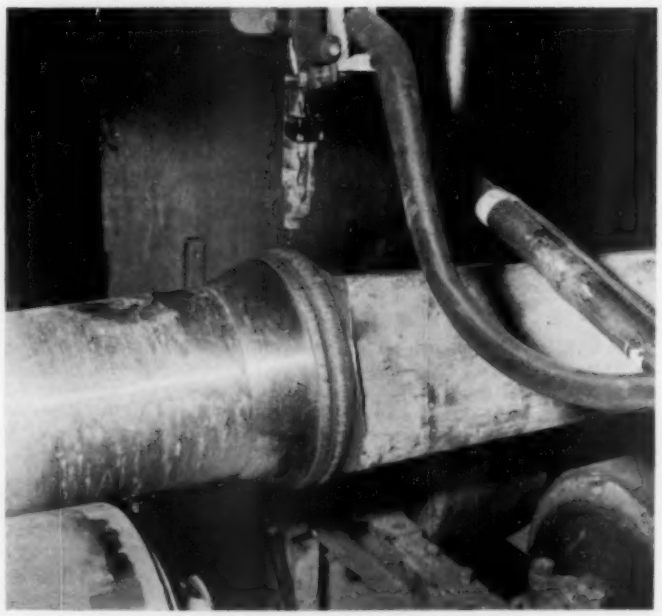


Fig. 5—Completed gas metal-arc weld in arm for a multiple hearth roaster

Smaller Sections for Convenience

As an example of how cast welding permits the use of smaller sections for convenience, the lead photograph shows the huge frame for the stern of the *S. S. Del Rio* made up of seven separate sections. Each of these is joined together permanently by thermit welding. Here welding offered the convenience of assembling at location rather than the costly shipping of bulky structures.

Dissimilar Castings

Weld-casting has proved useful for joining unlike castings. Thus in Fig. 3, two dissimilar castings—a high-pressure outer shell and full steam-chest—have been prepared for assembly. Expensive coring and pattern costs were avoided here by casting pieces separately, then welding them together.

Simplicity

Obviously the simplest way to produce the intercept valve casing in Fig. 4 was to fabricate it from component parts. Here, stub pipes were welded to

Fig. 6—Low-alloy steel dredge pump liner consisting of static castings welded together with AWS Type E7016 electrodes

Fig. 7—Bucket for draining wash material from pulp—consists of two castings which were welded together

the outlets by automatic submerged-arc welding and a flanged elbow was welded on by the manual submerged-arc process to the clean-out opening between the outlet pipes.

Circular Welds

Weld-casting is useful for joining circular parts. In Fig. 5, for example, the completed weld of a roaster arm (ACI Alloy HH) for a multiple hearth roaster consisting of a centrifugally-cast hub was

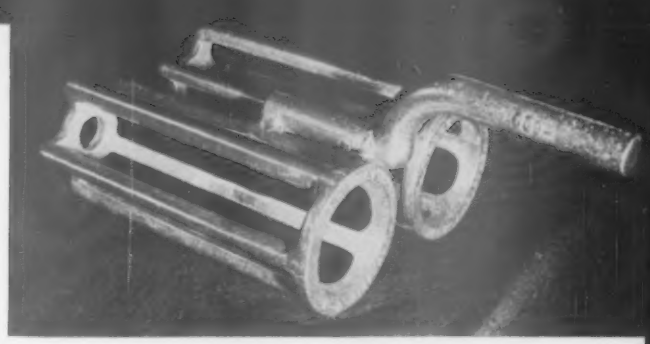


Fig. 8—Welded tong basket for handling nuclear fuel

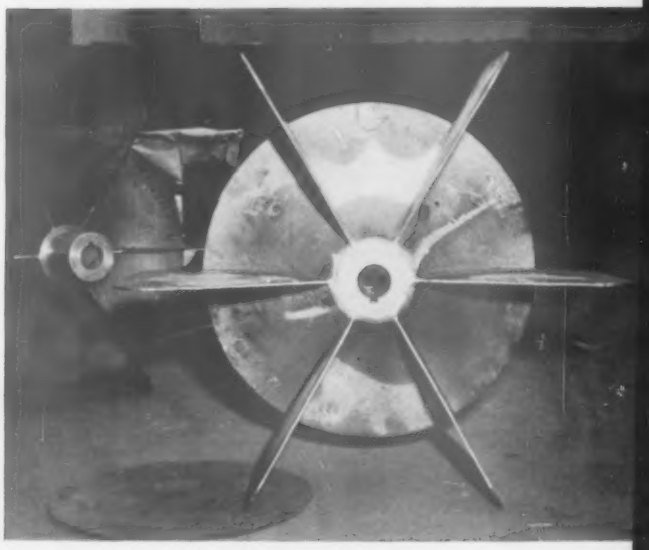


Fig. 9—Fan for driving sulfur fumes to outside air

welded with $^{1}/_{16}$ in. diam Type 309 stainless steel filler wire to a static cast arm by the automatic gas metal-arc process. The welding machine was set at 290 amp and 26 v. The shielding gas consisted of argon with 1% of oxygen and was supplied at a rate of 45 cfh.

A Still Bigger Casting from Two Big Ones

A perhaps self-evident advantage of cast-welding is its use to fabricate a "still bigger casting from two big ones." This is illustrated in Fig. 6 wherein two low-alloy steel castings were welded together with AWS Type E7016 electrodes to make a dredge pump liner. This application emphasizes the practicability of fabricating large units of any size or shape from smaller pieces.

Odd-shaped Pieces—No Problem

A good example of how to produce an odd-shaped piece inexpensively appears in Fig. 7. This is a bucket for draining wash material from pulp. Instead of being cast in one piece, it actually consists of two identical pieces welded together. Gas metal-arc welding was used with Type 316 stainless steel filler wire. The finished buckets were tested at 50 psi air pressure.

Tough Job Made Easy

In Fig. 8 is a welded assembly of a tong basket (ACI CF-8-C) for handling nuclear fuel. The as-

sembly actually consists of three elements. They were welded together with the tungsten-arc gas process using 1/8 in. diam thoriated tungsten electrodes, with 16 cfh of argon as the shielding gas, and 1/8 in. diam Type 347 stainless filler wire. As indicated here, welding is an obvious answer for many tough foundry jobs.

Prior Machining Reduces Cost

In Fig. 9 is an excellent example for illustrating how the machining of components can be done inexpensively compared to the costlier methods of a single solid piece. The fan in Fig. 9 for driving sulfur fumes to the outside air consists of a ACI CN-7M static cast hub and shroud with welded vanes. The vanes are Carpenter 20 rolled plate. Some machining operations can be completed before the welding together of these components.

Versatility—Forgings to Castings

In Fig. 10 is a volute casting in a pump to be used by the Navy for nuclear power cooling. The nozzle extension and skirt which is being welded are Type 304 stainless steel forgings. The versatility of creating any desired shape or contour is possible with welding techniques.

Fig. 10—Static cast Type CF8 pump volute for a Navy nuclear power primary cooling system. The nozzle extension and skirt (which is being welded) are Type 304 forgings

Fig. 12—Cladding or overlay deposition on a cast structure using the gas metal-arc process

Fig. 11—Extreme of composite weldments in which a casting comp ises a minor portion of the structure

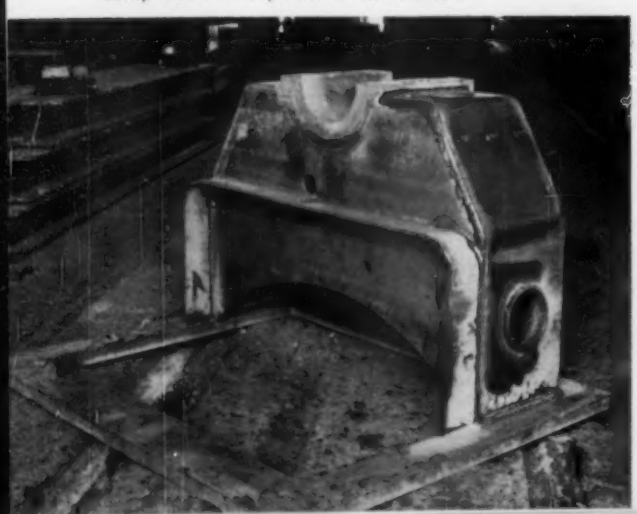
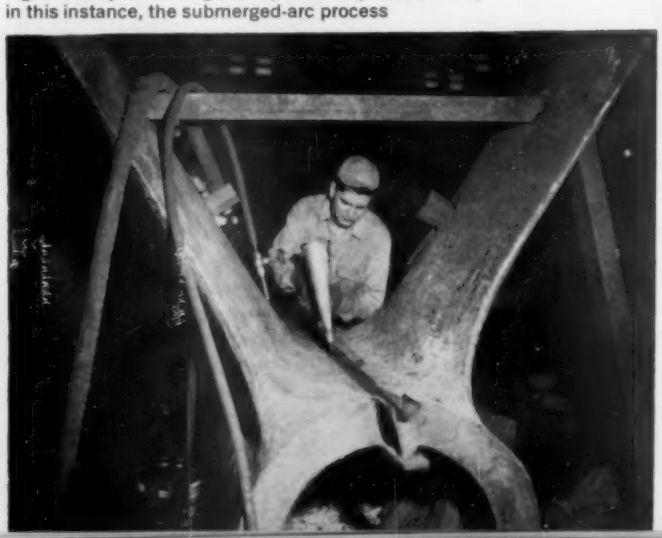


Fig. 13—Simple fixturing made possible by cast welding—in this instance, the submerged-arc process



Varied Contours Making up a One-Piece Assembly

An illustration of many composite weldments appears in Fig. 11. Note the different contours and shapes of this base and drive housing for a pump case; these are made into one tight unit—by welding. This weldment has simplified the casting design. A casting in this assembly comprises only a minor portion of the entire structure.

Overlay Deposits to Prevent Erosion

Cladding or overlay deposition by using the automatic submerged-arc process is shown in Fig. 12. Contours of the lip and edges of the spouts shown here were finished by manual gas metal-arc welding.

Simple Fixturing

A by-product of cast welding often is simple fixturing. Referring to Fig. 13, semi-automatic submerged-arc welding is the method used for this job. The strut arms are inverted, and the operator works from a scaffold when welding the diametrically opposite groove on the strut barrel. Manual guiding and simplest fixturing make this an ideal condition and application. Irregular shapes, too difficult to position under an automatic head, are also welded by this technique.

Cast-Welding Utilizes Low Cost Castings

As a good example of cast-weld construction, the two components on the left and right side of Fig. 14 welded together, making the completed piece in the center. Expense of coring was eliminated.

Components with Varied Physical Properties

The 50-ton runner for a reversible pump-turbine in Fig. 15 is a welded assembly consisting of these components: cast carbon-steel buckets, a cast crown and runner band. Stainless steel segments were welded to lower portions of the buckets for protection against pitting.

Pre-machining Lowers Fixture Costs

Three steel castings in Fig. 16 were welded to rolled plate sections to make this hoist drum. All joints were pre-machined and then submerged-arc welded.

Acknowledgment

The author wishes to express appreciation to the following organizations for permission to use the indicated illustrations: Allis-Chalmers Manufacturing Co., Fig. 15; Avondale Marine Ways, lead photograph; Birdsboro Steel Foundry and Machine Co., Figs. 11, 12 and 13; Esco Corp., Figs. 5, 6, 7, 8, 9, and 10; Falk Corp., Fig. 16; General Electric Co., Figs. 1, 2, 3 and 4; and Wehr Steel Co., Fig. 14.

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Fig. 14—Welded cast assembly (center) as fabricated from low-cost components (left and right)

Fig. 15—Welded 50-ton runner as assembled from several cast components

Fig. 16—Hoist drum assembled from three steel castings by submerged-arc welding

Purge Bar B in place for the finger end closure weld

The manufacture of sea water distillation equipment calls for unique welding, fabrication and inspection techniques when making a

Corrugated Monel **Heat Exchanger**

BY J. F. O'CONNELL, N. J. RITCHEY, AND J. C. STEWART

Introduction

During World War II and immediately following, there was an obvious need for an improved design of sea water distillation plant for shipboard application. This need led to the development of the "Basket Evaporator," the heart of which is the corrugated monel heat exchanger or "basket," shown in Fig. 1. This paper describes the unique design features of this component, together with recent improvements that have been made in the welding fabrication and radiographic inspection techniques for the basket.

Heat Transfer and Mechanical Design

Design and Performance Criteria

In designing shipboard equipment, particularly for military service such as in nuclear submarines and surface ships, reliability is a critical and primary requirement. This factor was considered along with the following design and performance criteria in the development of the basket evaporator:

1. A favorable water output to space and weight ratio.
2. Construction of materials that would resist corrosion by sea water and hot brine.
3. A configuration of primary heat transfer surface that would shed scale readily without requiring chemical feed treatment of the feed water.
4. Ease of operation and maintenance.

Over the years since the original concept of the basket evaporator, all of the above factors have been incorporated into the design with refinements to give the modern sea water distillation plant in Fig. 2, which illustrates a single effect unit with the shell door open to show the basket in place. Evaporators of this type are currently in service on certain nuclear submarines now in commission and on more than 400 other naval and merchant vessels in worldwide service as well as in several land installations in arid areas of the West Indies.

To illustrate how the basket fits into the evaporator process, a diagrammatic drawing is shown in

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Paper to be presented at the AWS National Fall Meeting in Dallas, Tex. during Sept. 25–28, 1961.

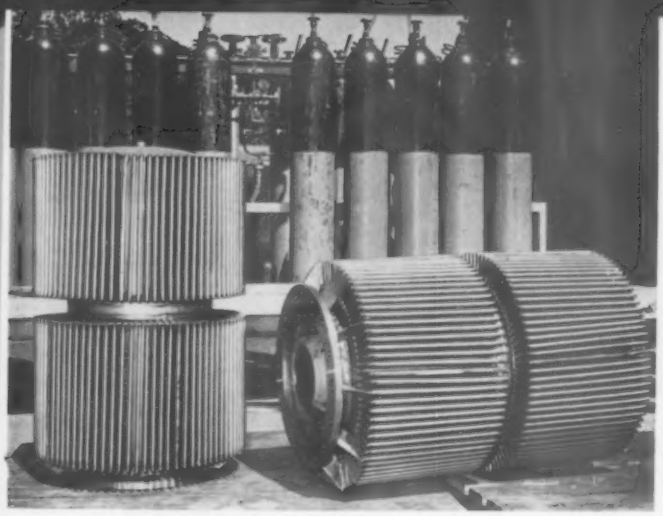


Fig. 1—Corrugated Monel heat exchanger or evaporator basket in the finished form

Fig. 3. This drawing shows a standard single effect basket evaporator with heat exchangers and pumps. The various flow cycles are evident by following the arrows.

Design Fundamentals

In developing the corrugated heat transfer surface, five basic fundamentals governing the design of heat exchangers for corrosive and scaling service, have been incorporated. These are:

1. Noncorrosive material and smooth heat transfer surface: Monel was chosen for its very high resistance to sea water corrosion. Although high in basic cost, this factor is balanced by the advantages of corrosion-resistance and high-strength characteristics. The smooth surface in contact with the boiling sea water retards scale build up in heavy layers. Therefore, a relatively low-scale heat transfer coefficient is maintained, and over-all heat transfer remains close to "bare surface" conditions.

2. High velocity circulation: A circulation baffle or "skirt" is fitted around the basket, as shown in Figs. 2 and 3, at a fixed distance from the periphery of the fingers to promote high velocity circulation of the vapor and brine along the heat transfer surface. The high velocity promotes better heat transfer by keeping the film coefficient at a minimum and discourages rigid scale formation. Violent boiling action takes place between the skirt and the fingers to give velocities in the order of 8–12 fps of vapor and brine upward to the top of the basket. The heavy foaming characteristic of the boiling sea water is utilized to produce a lower static head, to reduce the elevation of the boiling point and to promote high velocity circulation. Also, the velocity along the basket fingers has a scrubbing action which retards heavy scale formation. It is of interest to note that the primary steam inside the basket has a counter flow action to the vapor and brine which improves heat transfer.

3. Flexible heat transfer surface: The corrugated form of the heat transfer surface imparts the desired flexibility to the heat exchanger. The forming and fabrication of the corrugations will be described

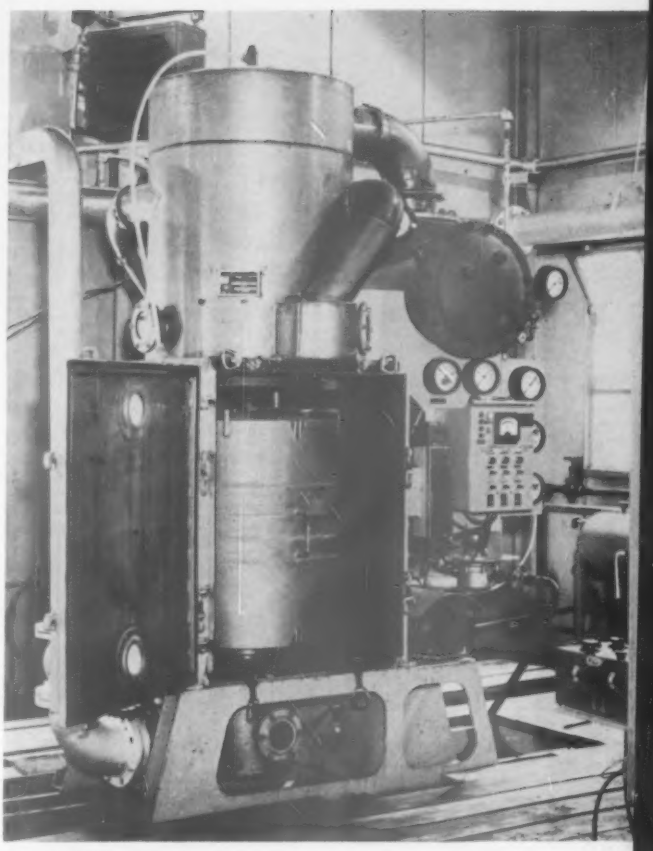


Fig. 2—Single effect basket evaporator similar to type installed on nuclear submarines, showing the basket in the shell with the circulation baffle in place

in detail below. During operation of the plant, small pressure fluctuations cause the fingers to "breathe" slightly; this sheds loose scale and discourages heavy scale build-up. After a prescribed period of operation it is usually desirable to thermal shock the basket to remove scale. During this operation, the fingers flex as much as $^{3}/_{32}$ in. due to the high vacuum produced in the basket and thus snap off the scale.

4. Low static head: because of the high velocity factor described above, it is possible to operate this type of unit with a low static head of brine in the boiling section. This condition reduces the temperature elevation necessary to bring the feed water to the boiling point. The water level is normally maintained between 3 to 6 in. above the bottom of the basket fingers; this gives a low submerged surface to total heat transfer area ratio and results in a high apparent heat transfer coefficient. In normal operation heat transfer coefficients in excess of 700 Btu sq ft/° F are achieved.

5. Low brine retention time: The upward flow of brine into the spill over brine removal system gives a very low retention time in contact with the

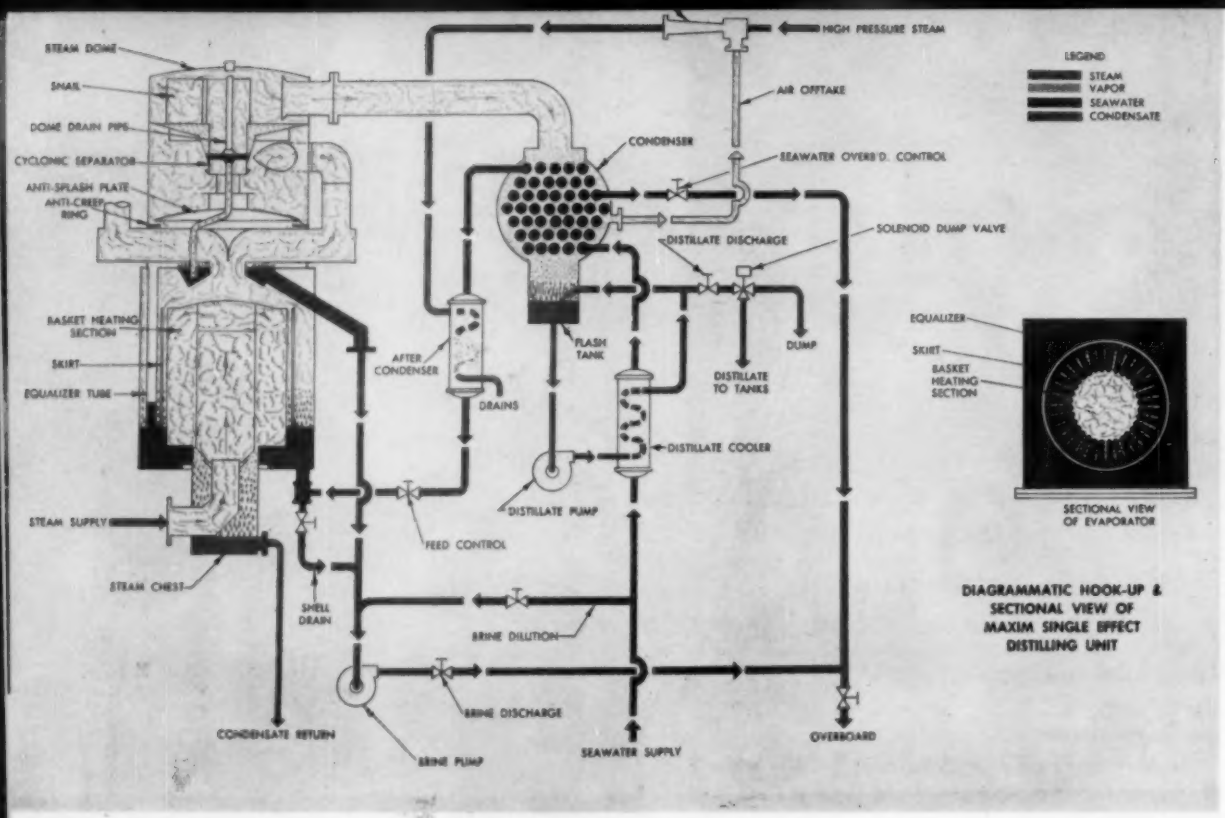


Fig. 3—Diagrammatic arrangement of single effect basket evaporator

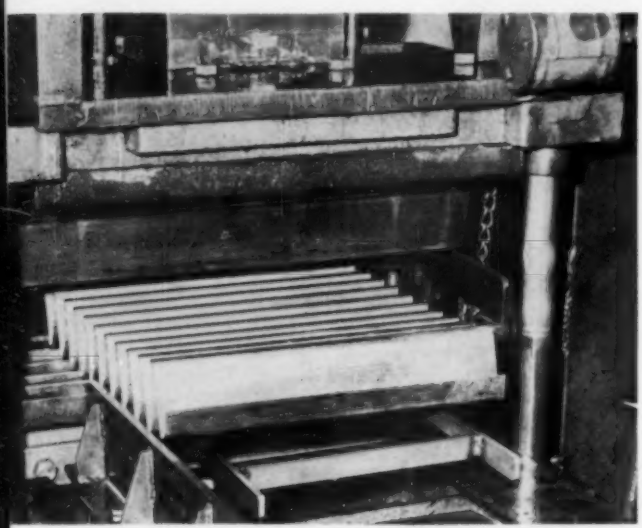


Fig. 4—Finger forming die showing a section being corrugated

heat transfer surface. The advantage of this feature is simply that the less time the scale-forming liquid is in contact with the heating surface the less scale precipitation that can occur. In standard basket evaporators, the brine retention time is in the order of fractions of a minute.

The baskets are designed for an internal working pressure of 15 psi and are hydrostatically tested at 30 psi. Tests have been made of the stability of the corrugations for all lengths up to 40 in. Under test pressures of four times the working pressure, there was no indication of instability. The sides of the corrugations bulged and took a slight permanent set. However, these act as flat plates, and the stress in this part of the finger is not affected by the length. It is more likely that failure would first occur as a flat plate stress in the sides of the corrugations rather than as a beam stress on the rigidity of the length of the corrugations.

Material Forming

The basket fingers are formed from 0.050 in. Monel sheets to a depth of 3 in. on a $^{5}/_{16}$ in. pitch. Standard widths of corrugated sections are 15 and 20 in., but developments are underway to produce sections in widths of 30 and 40 in. At the present time, the maximum length of Monel sheet available is 144 in. Therefore, because of this limitation, three to five sheets are required, depending on the basket size, to make the corrugated sections that comprise a basket. If Monel sheet could be produced as coil stock, a considerable saving could be achieved in fabricating costs, since only one handling and one closure weld would be required to form the basket. The finger sections are formed in the press and die shown in Fig. 4. This is a progressive forming die designed to give a minimum of metal drawing and thus maintain equal wall thickness throughout the finger sections.

Step two in the forming process is to compress the fingers in a rack with a press to obtain the 180

deg bend at the root and crown of each finger. Each section is then trimmed to give the required number of full fingers with half fingers at each end for welding to the adjoining section.

The final step in the forming process is to crimp the ends of the fingers for the closure weld. In earlier designs, the ends were closed with a radius die to bring the edges parallel to one another; the closure was made by fusing the edges together without filler metal. This has proved to be an unsatisfactory joint in service and, in the present design, the ends of the fingers are formed into a peaked configuration and closed with filler metal weld.

An improved die has been designed and is now in the final stages of test. This die forms the fingers by a folding process at a much higher speed than the progressive forming die. It can be adapted to handle 40 in. wide sheets. To make the die as fully automatic as possible, an attempt is being made to include end-closure forming dies and a trimming cutter to give a finished corrugated section as it comes out of the press.

Welding Equipment and Facilities

The first and perhaps most important factor to consider for welding special alloys, such as Monel, is cleanliness of the work area and atmospheric conditions. General shop welding areas, where smoke from metal-arc welding and grinding dust are present, are not suitable. Even perspiration on a Monel weld joint can give serious trouble. For this reason, a controlled atmosphere welding room was constructed and equipped with air conditioning and heating facilities. Figure 5 shows the welding room and the arrangement of equipment.

The four power sources are d-c rectifiers, with built-in high frequency gas and water solenoid valves, and time limit relay switches for prearc and postarc purging. The welding torches are 250 amp inert-gas units with $^3/_{32}$-in. diam thoriated tungsten electrodes. Each power source is equipped with a foot controlled rheostat which allows the operator to control the current as required. Also this control is used for arc decay to eliminate the crater at the end of a weld pass. The operator's foot pedal also controls the supply of shielding and purge gas. The flow of cooling water is constant, and a switch in the foot pedal operates the water solenoid valve to allow the helium to flow to the purge bar on the underside of the weld joint. Because of the tedious nature of this hand welding process, welding fixtures and stools are arranged for the most comfortable welding position to enable each operator to maintain the required weld quality throughout an 8-hr shift.

The use of copper purge bars for underside gas shielding of the weld joint was one of the most important factors leading to a satisfactory weld. The various types of bars used are shown in Fig. 6, and are identified as the bars for: A-longitudinal finger welds, B-end closure finger welds, and C-welding the flange-to-finger joint.

Considerable redesign has been made on the bars since first used. For example, Bar B originally permitted the gas to flow out from one or more holes directly under the weld joint. This design was unsatisfactory because gas pressure would build up

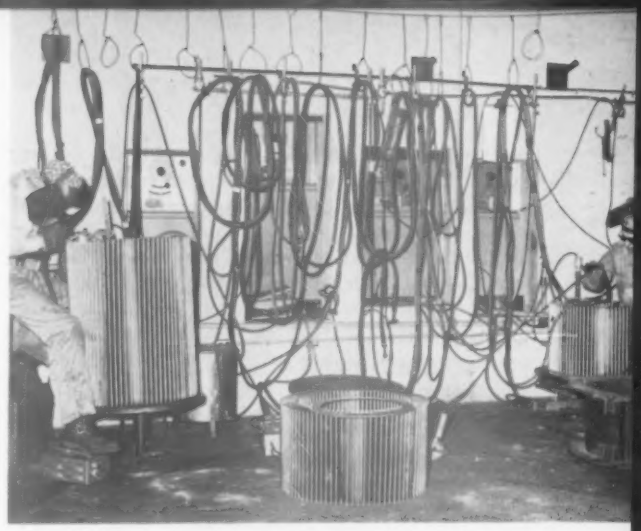


Fig. 5—Welding room showing gas tungsten-arc machines, welding lines, gas hoses and baskets in process of welding

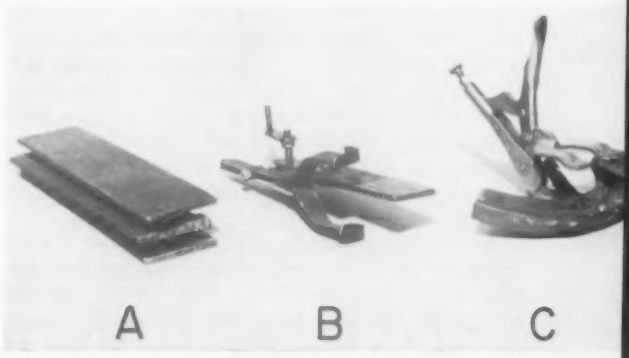


Fig. 6—Purge bars for underside gas shielding of the weld joint; A—for longitudinal finger welds; B—for end closure finger welds; C—for the flange-to-finger joint

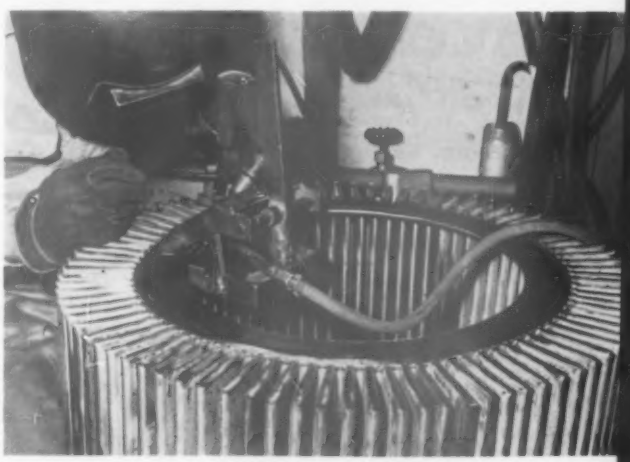


Fig. 7—Purge Bar C in place for the flange-to-finger weld

and cause either a blow-through during the welding cycle or it would leave a small depression in the underside of the weld deposit. To overcome this difficulty, one gas orifice only is used; this is located on the bar beyond the end of the finger. The hole is drilled at a 60 deg angle pointed back to the finger; this forces the gas under the weld joint without any localized pressure pockets. Purge bars in place for welding are visible in the lead photograph and in Fig. 7.

Welding Procedure

The J. B. Beaird Co. began to manufacture Monel basket heat exchangers approximately one year ago. Prior to this time, a number of baskets failed in service, primarily because of two factors—stress corrosion cracking and lack of penetration at the circumferential finger to head welds.

The stress corrosion cracking occurred in the finger closure welds which were fused together without filler metal. This type of weld contained microporosity due to the lack of adequate deoxidizers in the parent metal. The brine in the evaporator attacked this porosity and produced pinhole leaks and, in some instances, caused progressive tearing at the weld joint. Sulfur inclusions were found in some of the defective welds, indicating lack of cleanliness at the time of welding.

At the finger-to-head joint in the earlier designs, the weld was made with Monel filler rod from one side only. The underside of the weld was not adequately shielded, and full penetration was not obtained since fusing on the underside was not employed. Cracks developed at localized stress points, caused by lack of penetration.

These were the major problems that had to be overcome by redesign of the weld joints and revised welding procedures. The first step in setting up the manufacture of these components was to qualify the welders. Since the baskets were required to meet U. S. Navy standards and pass rigorous U. S. Navy inspection requirements, all operators were qualified to MIL-STD-248 (Navy) with tests witnessed by the local Inspector of Naval Material.

Welding procedures were established to the requirements of MIL-STD-278 (Navy) and qualified by the Bureau of Ships, Washington, D. C. To support this qualification, a prototype basket was fabricated and tested by the U. S. N. Engineering Experiment Station, Annapolis, Md. The test consisted of a simulated thermal shock or descaling cycle on a timed sequence to represent the flexing that the basket would undergo in actual service.

A hydrostatic test pressure of 30 psi for the baskets was maintained throughout the test. After a simulated period of 122 years of service, the test was discontinued and the basket examined but no trace of failure or weakness could be found in the weld joints. The test pressure was increased to 40 psi, almost 3 times the working pressure, and 19 more years of simulated service was obtained before a failure occurred as a tear in one of the longitudinal finger welds. Based on the test results, the Bureau of Ships was satisfied that the welding procedure was adequate to ensure reliability of the baskets.

After the monel sheets have been corrugated, trimmed and de-burred, the baskets are assembled and welded as follows:

1. Each section is immersed in a suitable cleaning solvent to completely degrease the weld edges. After removal from the solvent, the sections are blown dry with filtered compressed air.

2. The sections are laid flat on a fit-up table, and the longitudinal edges are clamped together for welding. Longitudinal purge bar A in Fig. 6 is clamped in place under the weld joint. Helium is supplied to the underside of the joint during welding at a rate of 20 cfh.

The weld is made in two passes. For the first pass, 85–90 amp and high travel are used with $^1/_{16}$ in. diam Monel filler rod added. The high travel avoids excessive sagging of the weld metal on the underside of the joint. The second pass is made without filler rod, at 95–100 amp.

The operators use a weaving motion to shape the weld and to ensure smooth and full penetration with the parent metal. This technique also gives a very even bead on the underside of the joint. The required number of corrugated sections to make a basket are welded together in this manner with final closure weld forming the drum shape of the basket.

3. In the next step, the sections are placed in a circular fixture which gives the required outside diameter for the finished basket. The flanges are held in place, and the fixture is tightened to compress the fingers and close up the gaps for the closure weld on the fingers and the flange-to-finger joint. Each flange is tack welded in place at several points around the periphery, and purge bar C in Fig. 6 is clamped in place. Helium is supplied to the underside of the weld at a rate of 20 cfh. For the first pass, the current is set at 110 amp, and argon shielding flow at 18 cfh is employed. The torch is held at a 45 deg angle, and the root bead of each finger is fused to the flange using a $^1/_{16}$ in. diam Monel filler rod. This procedure produces a fillet weld on the underside of the joint as evidence of adequate penetration. The purge bar is moved around the flange to complete the flange weld. Earlier attempts at holding the torch perpendicular to the weld surface produced a convex bead on the underside with a stress concentration area at the finger joint.

4. After the first pass in the flange weld is complete, the finger closure welds are made. Purge bar B in Fig. 6 is inserted under each finger in turn. The procedure for these welds is the same as described for the longitudinal finger welds; welding from the outer edge and working in to the flange. Although crater elimination is achieved by the foot-controlled rheostat, a deposit of weld metal is left at the termination area on the flange. A second

Fig. 8—Inside view of the basket looking toward the top head and showing fusion of weld bead on underside of fingers and flange weld joints

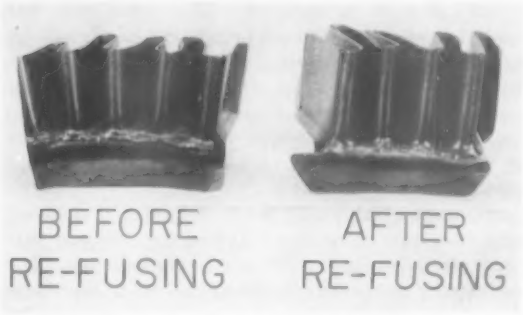


Fig. 9—Results of a bend test of an unfused and fused section of a flange-to-finger weld, showing the crack which occurred in the unfused sample

pass is then added to the flange weld, using filler metal to achieve good reinforcement. Again, on this joint, the operators use a weaving motion to shape the weld bead smoothly into the parent metal to prevent stress concentration areas being formed.

5. Both ends of the basket are completed in the same manner as described above. The next step is to fuse the underside of all the weld joints. This is accomplished by heating the weld bead, penetrating through each joint, and fusing the metal into the parent material to remove all stress concentration areas. This procedure must be followed cautiously to avoid undercutting. Figure 8 shows the fusion of the weld bead on the underside of the finger and flange weld joints. A bend test was made of an unfused and fused section of a flange-to-finger weld, and results are shown in Fig. 9. The unfused sample began to crack in the weld joint at approximately 60 deg of bend, while the fused sample showed no signs of weld failure when the flange was bent almost 180 deg.

This completes the critical welding of the basket components subject to flexing stresses. The next step is to subject all welds to radiographic inspection.

Repair of Weld Imperfections

When radiographic inspection reveals weld sections of unacceptable quality, usually the fault is either a gas occlusion or a tungsten inclusion. Because of the procedure used, it is very seldom that undercutting or lack of penetration defects occur. Gas pockets are removed with a carbide burr in a high speed hand tool. Tungsten inclusions are removed by using a small drill and drilling around the defect until the tungsten particle drops out. Depending on where the defect occurs, the appropriate purge bar is put in place under the defective area which is then re-welded, using filler metal to fill the cavity left by the grinding or drilling operation. When sufficient weld metal has been added, the filler rod is removed, the arc is allowed to decay, and the current is increased slightly to flow the repair metal into the original weld deposit.

Final Basket Assembly and Testing

When the basket sections have been cleared by radiographic inspection, the joining neck is welded to one section for a double section basket; the mounting neck is also welded to the other section, using an outside fillet weld and an inside corner weld. The two sections are joined with a similar weld. At this stage the unit is tested for pinhole leaks with air at 5 psi, using a leak detecting compound.

The completed basket is then stress relieved for 1 hr at 1000° F and air cooled. Stress relieving must be done in a reducing atmosphere to avoid embrittlement of the Monel.

After cooling, the basket is returned to the assembly area where the top dished head, mounting flange, internal steam tube and gussets, are added to complete the assembly. A final hydrostatic test is applied to the completed basket at 22 or 30 psi depending on the design.

Radiography

Initial Problems

Radiographic inspection of the basket evaporator was approached with considerable uncertainty as to the most effective method for revealing either internal weld discontinuities or positive indications of soundness. Radiography had been attempted prior to the current development work in basket fabrication but with indifferent success insofar as area coverage was concerned. With the conventional single-exposure technique, the radial distribution of finger sections made it difficult to record complete weld-image of more than two or three finger welds on one film. It was concluded that a fresh approach must be made in order to assure improved radiographic accuracy and, at the same time, to reduce prohibitive labor and material costs. Each basket section contains 180 finger welds in addition to flange and longitudinal welds, and the finger welds alone would require from 60–90 separate exposures. The variation in total number of exposures is due to minute physical distortion caused

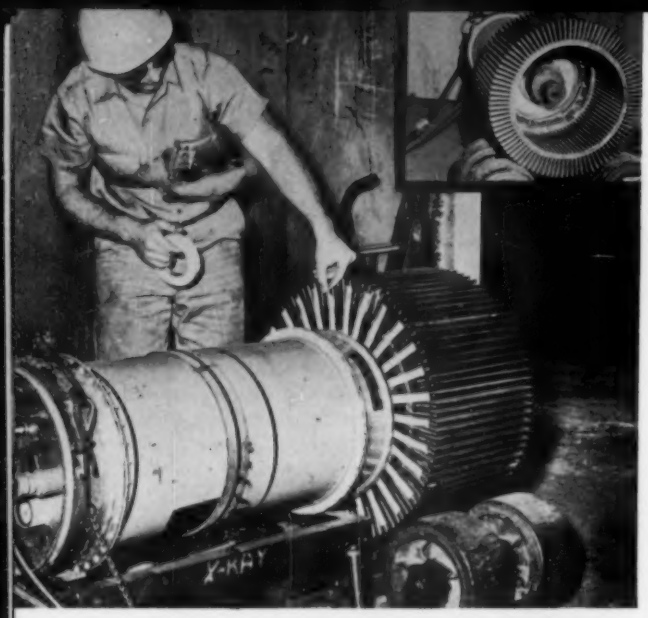


Fig. 10—Two views showing the Resotron X-ray machine in place for radiographic inspection of the basket finger welds

Fig. 11—Radiograph obtained using the Resotron X-ray machine for finger weld inspection. Exposure is a 14- by 17-in. film showing finger weld details

by the welding operation, and this factor sometimes made it impossible to record more than two welds on one film. While the degree of distortion is very slight, it is sufficient to detract from radial symmetry and, thereby, causes geometric difficulties in alignment of the beam of radiation with the plane of the welded area under examination. This was a serious problem, but it had to be solved if radiography was to be performed economically.

Preliminary work was begun with the purpose of establishing labor and material costs involved in using a directional or restricted beam of radiation as employed previously. This was necessary for the establishment of a basis for cost comparison with experimental techniques under consideration. Cost was not, however, the sole consideration; clarity of radiographic detail was the first goal to be attained if product quality was to be improved, and cost was of secondary importance. Although cost was considered to be secondary, the element of time required for radiographic inspection was vitally important insofar as it affected critical shipping schedules; therefore, a reduction in processing time was mandatory if schedules were to be met. It followed, that reduced processing time would inevitably make possible the reduction of labor cost.

Preliminary work was begun by radiographing a complete basket unit with General Electric OX-250 mobile X-ray equipment and employing a conventional single-exposure technique. Each exposure involved a painstaking and time-consuming set-up procedure because of the extreme accuracy required in aligning the beam of radiation with the limited area to be exposed. Fine grain film was used to assure optimum rendition of detail. A record was kept of set-up, exposure, film processing, interpretation, reporting, and filing time, and the resulting figures were discouraging. The elapsed time for each basket section was 7 hr at a total cost of $52.85 for labor and materials. It was obvious that radiographic inspection would be a major bottle-neck which could not be tolerated if shipping schedules were to be met. It was also obvious that production expense must be sharply reduced. The addition of overhead expense to the cost of labor and materials made the ultimate inspection cost prohibitive. Thus the development of a more economical technique was mandatory.

Development of New Radiographic Technique

Analysis of the situation indicated that the major problem to be solved was the exposure of finger sections so that a greater area of exposure coverage could be accomplished with a single exposure. As stated previously, radial distribution of the fingers, combined with minute physical distortion resulting from the welding operation, precluded the use of a directional beam of radiation. It was logical, therefore, to consider the possibility of using an end-grounded X-ray tube with 360 deg radiation emission. Theoretically, the 360 deg beam of radiation would be emitted in a pattern identical with the radial symmetry of the finger sections, and it was thought that this affinity recommended experimental work in this direction.

Existing X-ray equipment included a General Electric Resotron "300" with an end-grounded 360 deg tube, and it was decided to begin experimental work with this equipment. However, several potential difficulties appeared to create some doubt as to its ability to produce the desired result:

1. The tube-head diameter was 17 in. with the basket opening into which it was to be introduced varying from 14 to 16¼ in.
2. The source-to-film distance would be restricted

to approximately 10 in.

3. The usable band of radiation was only 20 deg in width.

One favorable feature was that the anode projected beyond the tube-head for a length of 7 in., and it was hoped that this projection would provide enough positioning latitude. The angle of target to electron beam was 90 deg, with the center of the beam occurring 20 deg above the plane of the target; this target angle directed the beam of radiation slightly to the rear and was ideal for our purposes.

A basket section was positioned lengthwise on a set of idler rolls, with the basket opening facing the tube-head, which was placed in a horizontal position. The tube-head was then raised, by improvised blocking, to a height which brought the anode to a central position and equidistant from all finger welds. The basket could be rotated on the rolls so that placement of film could be accomplished without difficulty. A jig was constructed later which permitted forward and backward motion of the tube-head without alteration of a preset height, and which provided ease of handling with reduction in set-up time. Figure 10 illustrates this arrangement.

Consideration was given next to size and type of film to be used, and it was decided that, if theoretical conclusions were correct, 14 x 17 in. Kodak Type AA would suffice. The Resotron "300" offers a range of 75–300 kvp and 2–7 ma so that a wide choice of exposure variables was available. However, the ultimate in contrast and definition was desired, so a kvp range of 100–150 and a ma range of 5–7 was selected for experimental exposures. The source of radiation was introduced into the basket opening to the extent permitted by the limiting diameter of the tube-head, and a series of exposures were made. The results confirmed original theories, and a final technique of 135 kv, 7 ma, 30 sec exposure, was chosen as the most effective combination. Due to the comparatively short source-film distance, a slight distortion of radiographic image was noted, but its degree was not considered to be objectionable. Subsequent exposures indicated that the slight distortion accentuated rather than obscured internal defects and, in the interest of other advantages of the technique, it was decided that the condition could be tolerated.

Each 14- x 17-in. film clearly defined 22 finger welds as compared to two or three recorded by original techniques used. The basket circumference was divided into 10 areas of 18 fingers each; this provided an overlap of two fingers on each end of the film, and fingers were numbered in groups of three for purposes of identification. This identification system was found to be effective for ease in locating unacceptable discontinuities for repair operations. Figure 11 illustrates a typical finger weld radiograph.

Discussion of longitudinal and flange-to-finger weld radiography is not necessary, since conventional techniques are used for this phase of the radiographic inspection procedure. However, Fig. 12 is included to illustrate flange-to-finger weld quality.

Interpretation Standards

Establishment of standards for interpretation of radiographs was accomplished by the joint efforts of the authors, who pooled welding and radiographic experience to determine limits of acceptability. The local Inspector of Naval Material gave very valuable advice regarding tentative interpretation standards which would meet rigid U. S. Navy specifications. Due to the critical reliability factor of distilling plant service on board Naval vessels, only minute weld discontinuities could be tolerated. The factors involved in an acceptable weldment have been discussed in previous sections of this paper; therefore, further discussion is unnecessary. Throughout the welding and inspection phases of manufacture, the radiographic and functional quality of the basket heat exchanger is controlled by standards established to satisfy Naval inspection requirements.

The technique employed for radiographic inspection of finger weldments is considered to be unique, and the foregoing description is offered for its possible value in similarly difficult applications.

Conclusion

When this manufacturing program started, the initial problems were due primarily to operator inexperience. Initial radiographic rejects ran as high as 20 to 35%. As the operators became more adept at manipulating the torch, adjusting the current, and maintaining the correct arc length, the percentage of rejected welds was reduced sharply. In normal production, the X-ray rejects now average 2 to 4%; this is considered to be a good level of production efficiency in view of the rigid inspection requirements. The improvements in the radiographic technique have made possible a 60% reduction in inspection handling time and a 53% reduction of radiographic costs.

Solving the problems which have arisen in the production and inspection of the corrugated Monel basket heat exchanger has been a challenging and rewarding experience. It is hoped that the techniques described in this paper have been of interest and value to the welding industry.

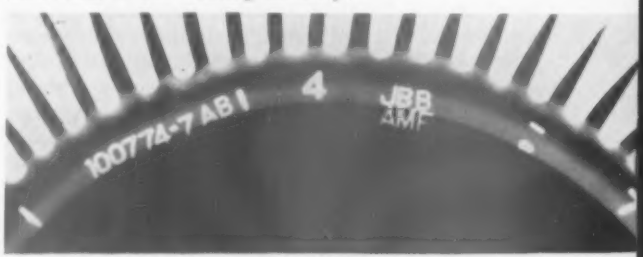


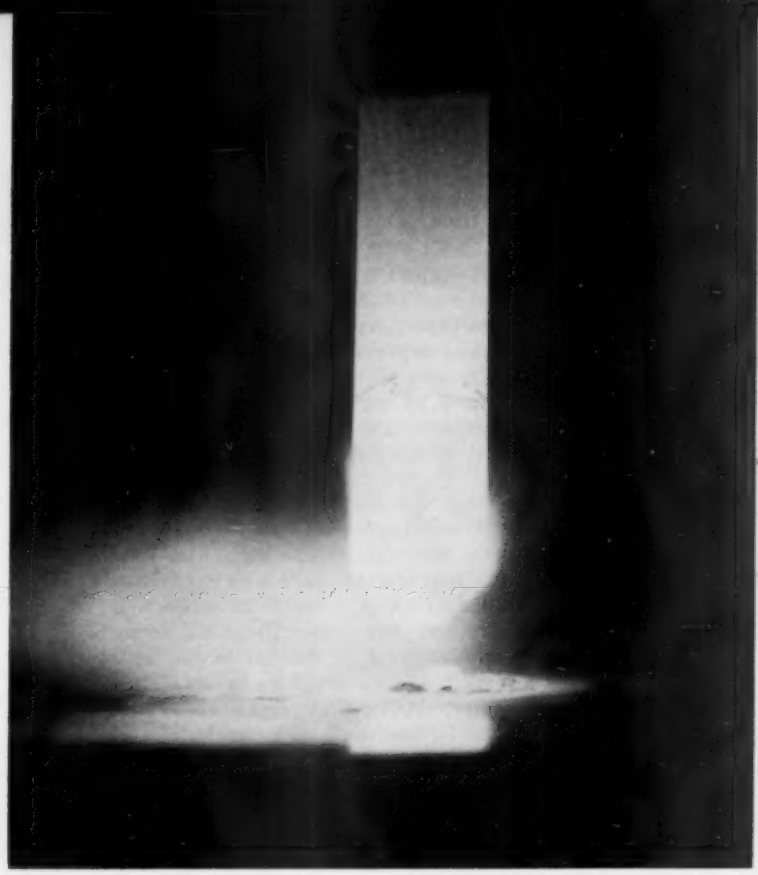
Fig. 12—Radiograph showing weld details of a flange-to-finger weld joint

The causes and relief of arc instability are investigated from a manufacturing aspect in

Electrical and Metallurgical Factors Influencing Welding

Arc Stability

BY JERRY E. GINN



Unstable arc condition

SYNOPSIS. Elimination of erratic arc operation was required for production welding of missile components by the inert gas tungsten-arc fusion process. Several studies were conducted to determine the primary causes of arc instability and the methods of forestalling its occurrence in welding stainless steel and low carbon alloy steel. This investigation was directed toward providing a practicable manufacturing process rather than attempting theoretical explanation of phenomena.

The three major factors that affect arc operation are material properties, tooling and field forces. These factors and methods of eliminating each are discussed in this paper.

Introduction

The increasing complexity and consequent cost of space-age assemblies demand that fabrication techniques be as "fail-proof" as is humanly possible. Usage factors, such as temperature extremes and weight limitations, and reliability factors preclude other than a "perfect first try" assembly. These elements have contributed to the increased use of inert-gas-shielded tungsten-arc welding. This joining process is nearly ideal for weldments on which quality and precisely controlled contour are paramount. Automatic voltage control affords precise and consistent results. However, arc instability or "arc blow" repeatedly upsets the inherently smooth and reliable operation of the system.

Automatic control of tungsten arc welding, as well as fused metal geometry, is dependent on an arc which provides a stable conducting medium. Arc length is controlled by measuring the potential drop between the electrode holder and the workpiece; melting occurs at that point which is the shortest electrical distance from the electrode. The thin gage (0.010 to 0.150 in.) of materials under consideration and the high quality required constitute a situation in which arc blow is synonymous with failure.

This investigation was conducted in an effort to provide a dependable manufacturing process; hence, all research was directed to manufacturing requirements. Because no alternating current welding is used in the surveyed facilities, all work was done on available, direct current, straight polarity equipment. Tests were performed on stainless steels and low carbon alloy steels of 0.080 to 0.140 gage, because most problems occurred on these materials.

A review of information concerning past arc blow problems revealed that arc instability occurred under unrelated conditions. Three distinct problem areas were apparent: (*a*) properties of materials being joined, (*b*) tooling materials and configurations and (*c*) field forces. The following paragraphs detail the causes, effects and controls of each problem.

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AIEE sponsored paper presented at the AWS 42nd Annual Meeting held in New York, N. Y., Apr. 17–21, 1961.

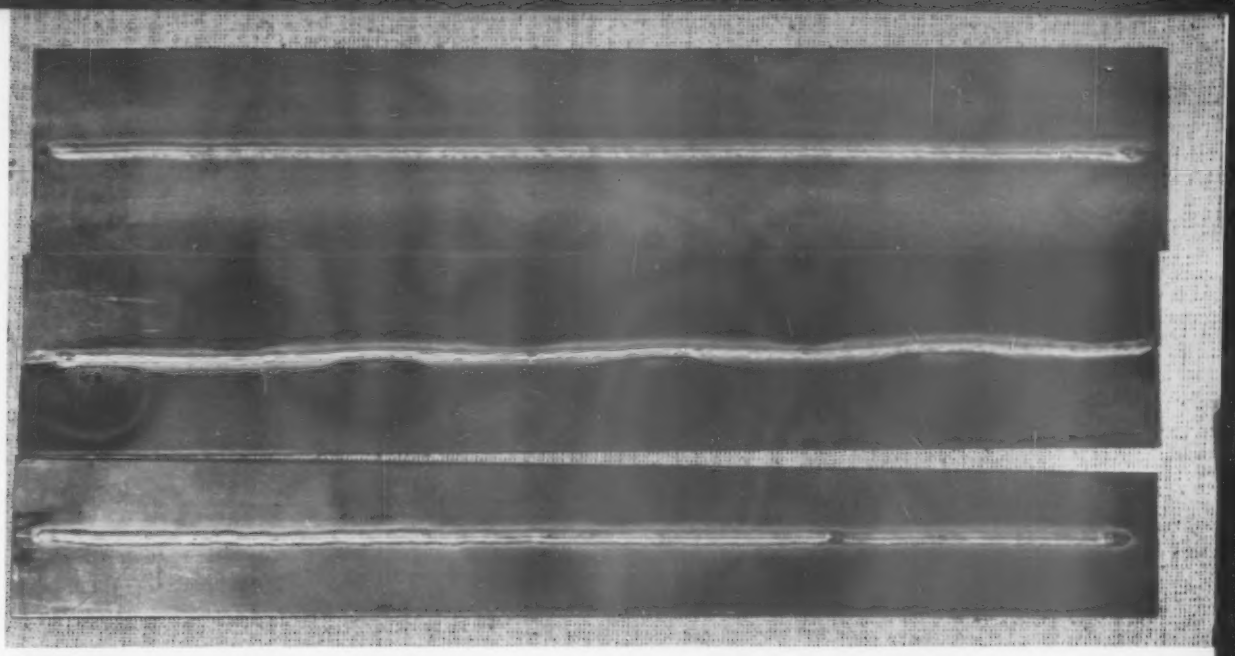

Fig. 1—Effect of heat-affected areas on arc stability

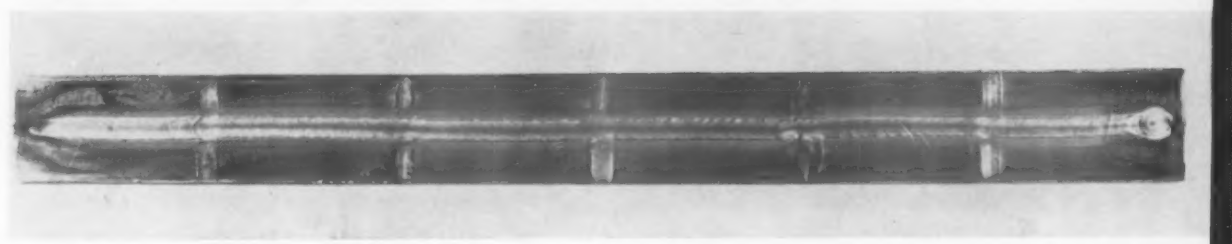

Fig. 2—Effect of thermal hardening on arc stability (4330M)

Material Properties of Low Carbon Alloy Steel (4330M, 0.080 In. Gage)

Heat-affected Zones

To determine the influence of heat-affected areas on arc stability, the edges of low carbon steel alloy plates were spot heated to 1000° F and air-cooled to ambient. The heated areas were approximately $1^1/_2$ in. wide and $1^1/_2$ in. apart. The plates were butted together so that the heated zones were opposite the unheated zones. During welding, the arc was repelled by the heated zones; this is illustrated in Fig. 1B. Surface resistance tests showed that heated zones had an electrical resistance of approximately 5000 micro-ohms, as compared with 500 micro-ohms on the unheated zones. Similar parts that were grit-blasted (Fig. 1A) or pickled (Fig. 1C) did not deflect the arc. This indicates that electrical and thermal resistance of the surface oxide is a source of arc instability.

Work Hardening

An unbalanced condition involving work hardened and annealed material was created by arranging patches of 50% hydrospun reduced material alternately with annealed patches. Parts were cleaned with methyl ethyl ketone. The welding arc was deflected toward the hydrospun patches. However, on hydrospun parts that were pickled in muriatic acid and annealed parts that were pickled in nitric-hydrofluoric acid, the arc was not affected. Again, the surface condition was the factor affecting arc operation.

Thermal Hardening

Alternate portions of steel plates were heated to 1500° F and quenched. This yielded a hardness of Rockwell C50 on heated portions compared to C18 for the unheated portions. Surface oxides were removed prior to welding. The arc showed no indication of instability. A panel processed in this manner is illustrated in Fig. 2.

Mill Scale

The light portions of the plate shown in Fig. 3 were reduced 0.002 in. on each side by chem-milling; the plate was then pickled in hydrochloric acid. During welding, the arc definitely attracted to the mill scale. Surface resistance tests indicated that the chem-milled areas had 35 micro-ohms resistance,

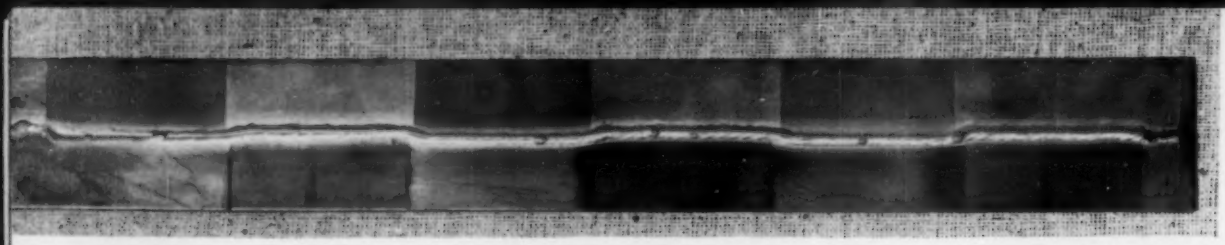

Fig. 3—Effect of mill scale on arc stability (4330M)

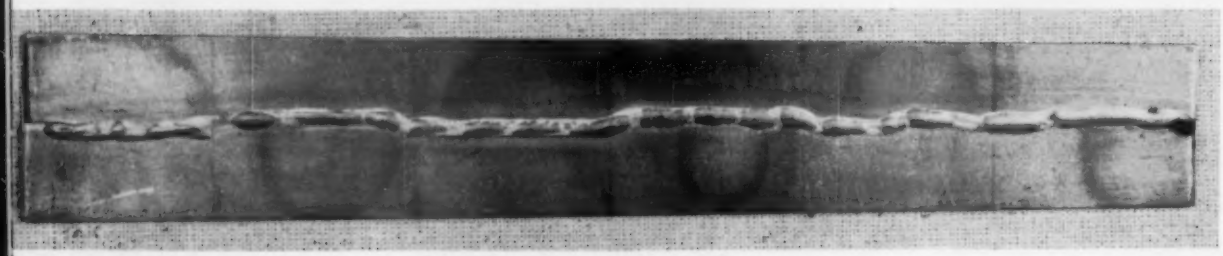

Fig. 4—Effect of surface oxides on arc stability (17–7 PH)

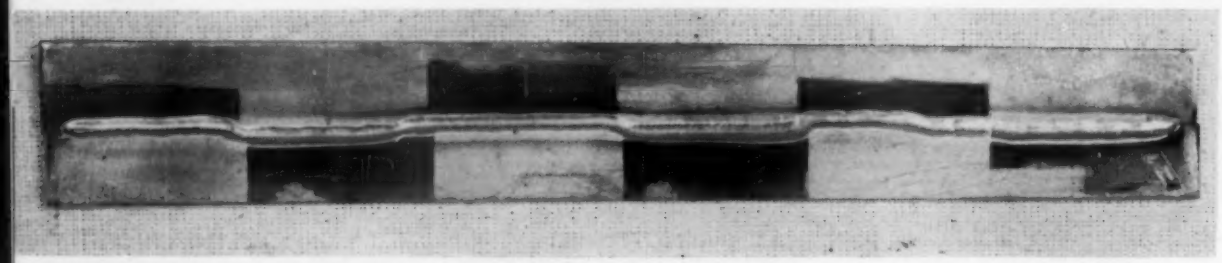

Fig. 5—Effect of grain structure on arc stability (17–7 PH)

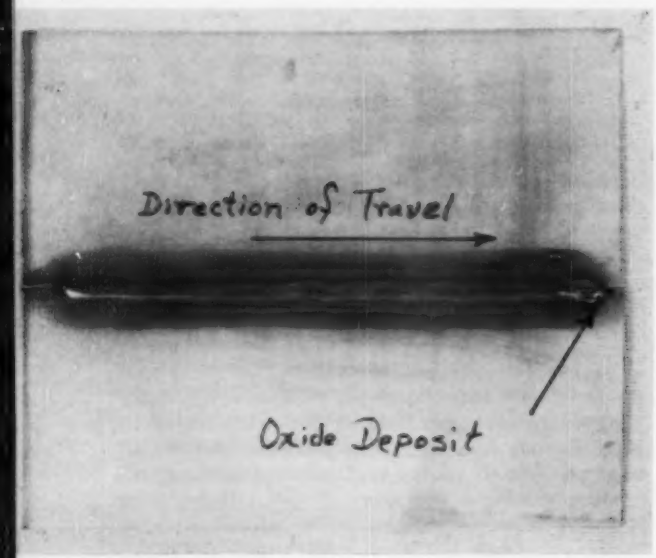

Fig. 6—Effect of oxide "spot" on arc stability (17–7 PH)

while pickled areas had 80 micro-ohms resistance.

Results of the above tests indicate that surface condition is the only material property of 4330M alloy steel which will cause unstable welding arc operation.

Material Properties of Stainless Steel (17 – 7PH, 0.100 Gage)

Heat-affected Zones and Surface Oxides

Stainless steel plates were heated and welded as the alloy steel was. The welding arc was attracted to the oxidized areas as shown in Fig. 4. This instability occurred only on certain heats of material; other heats displayed a complete indifference to surface oxide. Analysis of the base metal indicated that the percentage of aluminum has a bearing on this condition. Four heats were analyzed: those containing 1.22 and 1.21% aluminum reacted to the oxide, but those containing 1.14 and 1.11% were unaffected. If the greater aluminum content is the cause for response, there is still the question of why the arc deflects to the oxide instead of the lower resistance, pickled surface (5000 micro-ohms as opposed to 120 micro-ohms). The most striking difference in oxide composition is that the oxides attracting the arc contained 21.5 and 25.3% chrome, while those not affecting the arc contained 5.3 and 17.8% chrome. Perhaps the conductivity of the affecting oxide increases at the elevated temperature present in the welding arc.

Grain Structure and Magnetic Properties

To determine the effect of grain structure and magnetic properties on arc stability, two stainless steel plates were heated to 1400° F for $1^1/_2$ hr and were cooled to 60° F. This treatment produced

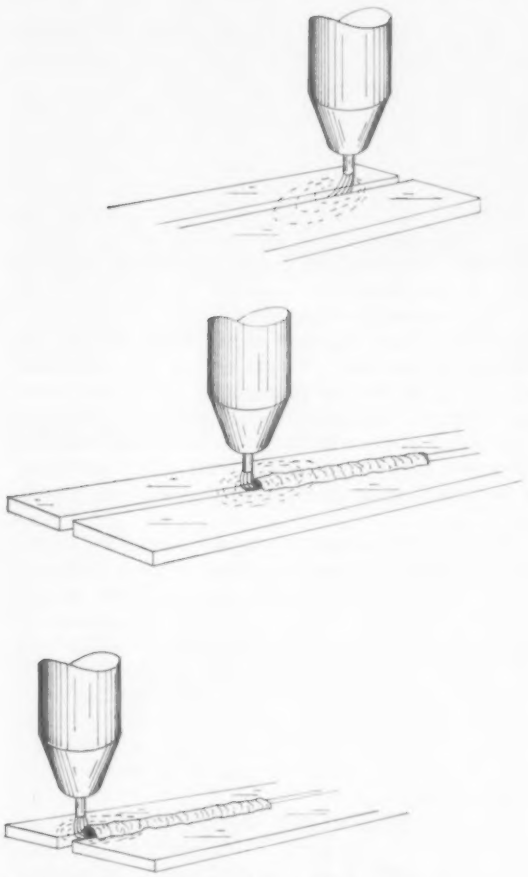

Fig. 7—Arc instability caused by field distortion

a martensitic structure of Rockwell C35. Alternate areas of the plates were then annealed to Rockwell C12. All oxides were removed from the plates before welding. The arc was attracted toward the martensitic structure as shown in Fig. 5. This indicates that grain structure is an influencing factor in arc stability.

Oxide Spot

During the foregoing tests, it became apparent that erratic arc operation resulted from the entrainment of a "slag" or oxide spot in the molten pool ahead of the electrode. As the oxide spot moved to one side, so also did the arc and the weld bead. The effects of oxide spot are illustrated in Fig. 6. In severe cases, the deflection of the arc was so great that lack of penetration resulted. Analysis of the oxide spot revealed a composition of 38% aluminum, 18% iron and 2% tungsten; these were the only elements for which it was tested. Tests at elevated temperatures indicate that an oxide of such composition may have less resistance than the molten steel has at welding temperature. Problems occurred on heats of higher aluminum content; it is this content that aggravates the arc-blow tendency on 17 – 7PH.

In an effort to improve arc stability, several commercial fluxes and several "concocted" formulas were applied to the weld joint. These preparations offered no marked improvement or advantage.

Tooling Materials and Fixturing Configurations

It is often said that a weld is only as good as its fixturing. This is particularly true of airframes and flying tankage for which it is necessary to produce welded assemblies within tolerances of a few thousandths of large footage dimensions, to control mismatch to a few percentage points, to provide continuous contour, and to control heat-affected zones with tooling configurations. Because of these requirements, parts must be rigidly held in the immediate area through which the arc travels. This is probably the greatest source of arc blow problems.

Tooling that is designed and fabricated for particular applications sometimes lacks electrical continuity. Such tooling will distort the field of the arc as the electrode passes along the welding joint. Whenever practicable, nonferrous materials such as copper and aluminum are being used in that part of the tooling which is closest to the arc. When this application is not feasible, 301 steel can be substituted. Magnesium is finding increasing use as a replacement for mild steel in primary fixture structure. These selected materials are all nonmagnetic, because magnetic tooling has such a great effect on the welding arc. Though this effect can be temporarily corrected by reverse polarizing, the chance of ruining assemblies makes magnetic tooling a most costly risk.

Tooling configuration is a greater source of trouble than tooling material is. As welded shapes have become more complex, the number of fixturing components that contact the welded assemblies have increased. This has led directly to the two tooling conditions which cause arc instability: field distortion caused by lack of contact with back-up support material, and field distortion caused by air gap between holddown "shoes" or "fingers." Though these may seem to be obvious problems, their combined effects can be baffling. The proper design assures intimate contact with back-up at all points, and minimizes air gap between "fingers."

Heated tooling presents no particular problem if proper attention is given to the field influence. Infrared tubular lamps have been used in the welding development of steel pressure vessels without discernable effect on the arc. Induction heating can be successfully used with proper coil configuration and location; the latter is usually some distance in advance of the electrode.

Evaluation of Field Forces

It is sometimes impossible to avoid long arc lengths in automatic tungsten-arc welding because of an assembly procedure or the necessity of producing a particular bead configuration. In these

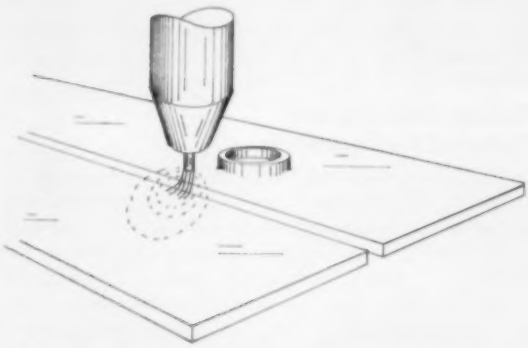

Fig. 8—Arc instability caused by nonsymmetrical welding assembly

Fig. 9—Arc oscillating transducer

situations, field effects are particularly apparent. Design geometry of parts being joined is seldom considered from a welding standpoint.

Field distortion tests indicate that the weld joint need not be pressed into contact; however, it must be in close contact. Figure 7 illustrates this situation. At the beginning of the weld, lack of field symmetry results from lack of metal beyond the end of the plate; this causes the arc to deflect forward. As the electrode progresses, the air gap in the plates, as opposed by the cast weld behind, causes greater reluctance in advance of the electrode; thus, the field is distorted and the arc deflects to the rear. At the end of the weld, lack of material at the end of the plate causes even more field distortion and greater arc deflection to the rear. Closure of the plate gap will eliminate the field distortion in the center of the weld. End symmetry is achieved, often unwittingly, by the use of run-out tabs.

Figure 8 shows field dislocation caused by asymmetrical metal distribution. Reluctance is increased in the region of the circular opening, and the arc deflects away from the opening. The importance of this deflection depends on the weld schedule and the extent of deflection. This problem can be alleviated by temporarily filling the opening with a close fitting plug of conductive material. The "filling" material can be determined through experimentation; hole size and boss configuration must be considered.

Magnetic manipulation of the arc has been explored for two purposes: to improve arc stability in welding 4330 steel and to achieve improved welded properties in aluminum. By clamping a transducer on an electrode holder, as shown in Fig. 9, it is possible to oscillate the arc in a frequency range of 3 to 10 cps. As expected, the arc deflection was normal to the field of the laminated electromagnet. Polarity reversal allows considerable deflection of the arc to either side of the electrode. The range of deflection was limited by automatic voltage control. Deliberate deflection of the arc caused the apparent arc voltage to vary; the voltage control picked up this variation. A sensitivity control allows a variation of 0.2 v. With greater signals, voltage control hunting becomes a problem. Slight oscillation improves both the top and the bottom bead configuration on 4330. Magnetic manipulation produces welded properties of aluminum comparable to those obtained under normal conditions. Because this procedure is so complex it has little more than novelty value.

Acknowledgment

The author is indebted to Thomas Smith, Robert Weishaar and Lyle Torpey, the welding engineers who conducted many of the experiments described in this paper.

Practical Welder and Designer

Skill with a Skillet

BY R. W. BRANDENSTEIN
AND J. A. WENDEL

Kitchens are marvels of automation, thanks to such devices as electric skillets, coffeepots, toasters, roasters and can openers. A step or two behind these wife-savers are the mechanized assembly lines which make them economically possible. Since nearly all appliances are metal, many production lines integrate electric welding processes.

General Electric Co. at its plant in Brockport, N. Y., produces modern electric skillets with a gas tungsten-arc spot-welding fixture. The spot welds join Everdur terminal pins to stainless steel dead-end pins to provide a plug where the control and power cord attaches. Everdur outer pins improve electrical conductivity at the plug while stainless steel core pins furnish the requisite strength. To permit complete immersibility of the skillet during washing the all-welded assembly must be absolutely waterproof.

High speed and reliability are features of the spot-welding fixture. Actual welding time is only 6 sec for both welds. Reliability is assured by: (1) accurate positioning in the fixture, (2) push-button control of the welding cycle and (3) pilot arc starting.

A pilot arc keeps the thoriated tungsten electrode in the spot-welding torch hot and ready to fire instantly, whenever welding current is applied. At the start of a work shift, the operator scratch-starts the pilot arc. A 5 amp current then flows continuously during the work day, as a small outflow of argon shielding gas protects the electrode. Incandescent gas within the nozzle keeps the electrode hot for instantaneous weld starting. Compared to high

R. W. BRANDENSTEIN is Advance Manufacturing Engineer, Housewares and Commercial Equipment Div., General Electric Co., Brockport, N. Y.; J. A. WENDEL is Technical Sales Representative, Linde Co., Div. of Union Carbide Corp., Buffalo, N. Y.

Fig. 1—Exploded view of connector plug shows Everdur terminal pin, stainless dead-end pin, spacers and water-tight cap

Fig. 2—Gas tungsten-arc spot welding in this automatic fixture completes fusion welds on two-pin assembly in just 6 sec

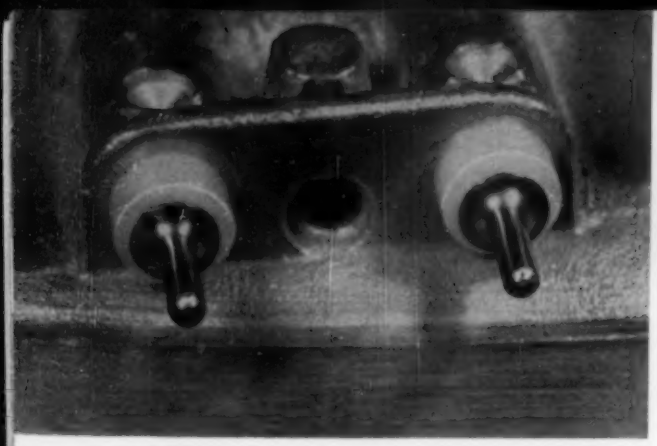

Fig. 3—Tungsten-arc welded pins require no finishing or pull-tests. Entire assembly is waterproof for complete immersibility

Fig. 4—Modern skillet brings automation to the kitchen. Sausage and eggs cook to a turn without sticking

frequency ac starting, pilot arc starting eliminates high-frequency interference problems, avoids electrode contamination (lasts 400% longer) and greatly improves process reliability.

Pre-weld preparation consists of removing magnesium oxide from the 0.090-in. diameter dead-end pins on the heating element. Parts are then assembled and the vessel is placed in the welding fixture The torch comes down over the pin and makes two fusion spot welds in six sec. Welding current is 80 amp, dcsp; argon is the shielding gas. No post-weld cleaning is required

Previously, General Electric joined the pins by induction brazing—a method with several disadvantages that are eliminated with gas tungsten-arc spot welding. Under the former method, brazing alloy and flux had to be inserted between the two pins. Quantity of flux and size of the alloy slug were difficult to control, resulting in tolerance problems and unsatisfactory joints. With internal joints, 100% pull-tests were necessary on all brazed pins. In some cases the pull-tests resulted in damage to the terminal assemblies, requiring reworking and rebrazing.

With automatic gas tungsten-arc spot welding, all joints are not positively attached, so that no pull tests are required. Weld quality is uniform and consistent tolerance is obtained.

Nickel-Silver Alloy with Automatic Fluxing System Beats Production Problems

BY LEE S. WADE

When confronted with the selection of a joining method for small, highly accurate, rugged components for the world's largest line of stapling machines, Bostitch, East Greenwich, R. I., selected nickel-silver brazing with an automatic fluxing system. In the case of one subassembly, both spot and gas tungsten-arc welding were first tried and rejected. Production brazing with the nickel-silver alloy and the automatic fluxing system saved Bostitch nearly $1000 in time, labor, materials and finishing costs in just one of many brazing applications presently in operation.

Among the specifications that had to be met by the joining method and filler alloy were close tolerances—to 0.002 in., post-joining heat-treating operations to 1600° F on small intricate parts fabricated from several different steel and copper alloys, no heat distortion, constant alignment during the manufacturing operation, and high-strength bonds that would withstand rugged pounding and vibration during the life of the product. Finally, each part had to have a minimum of aftercleaning and finishing and be ready for chrome plating.

When production first began, it was discovered that spot welding did not meet tolerance specifications and tended to crush delicate parts. Gas tungsten-arc welding was too expensive, because the parts were not designed for this particular method and there would be additional finishing operations. "Nickel-silver" brazing was the solution. Samples were tried, and the most suitable alloy was selected. The "nickel-silver" alloy chosen is designed to replace all conventional bronze, steel and cast-iron brazing rods for torch application. Designed to join over 14 different metals in any combination, the alloy's use in tool-tipping and high-alloy tool steel repairs meant that Bostitch's heat-treating operations would not affect the alloy.

Designated as No. 11 nickel-silver rod, the alloy melts at 1630° F, flows at 1750° F and develops average tensile strengths of 70–0,8000 psi and shear strengths of 120–160,000 psi. According to Joseph Kendzia, welding foreman for Bostitch, this alloy

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may be used in all positions—flat, vertical or overhead—without fuming or over-heating the base metals. As a result, warping and stress relieving are eliminated. Mr. Kendzia also notes that only one-third as much of the alloy is needed as ordinary bronze brazing rods or fusion welding rods to produce adequate bonds.

Joseph Kendzia discovered the brazing alloy while reviewing published case histories in the technical press. The article also gave details on the use of an automatic production fluxing system. In the Bostitch assembly line it was discovered that the flux-in-flame principal eliminates time-consuming flux dipping and brushing; the dispenser is connected directly into the fuel gas line between the acetylene tank and the torch. The water-soluble borate flux easily washes off the brazed part, eliminating special aftercleaning operations. Resulting bonds show good capillary action with no discoloration of the brazed joint and base metal.

As testing proceeded with satisfactory results, Mr. Kendzia, working with Stafford Lacy of Auto Battery & Electric Co., New London, Conn., installed the new method, and subsequently called in Al Heaton of Corp Brothers, Providence, R. I. and our regional manager, to set up a pilot production operation. The following series of operations were established as typical of the many present uses Bostitch makes of the brazing alloy and automatic fluxing system.

A cold-rolled Stanley L-5-C steel channel (with the analysis of 0.24–0.31% carbon, 0.040% maximum phosphorus, 0.10–0.025% silicon, 0.30–0.60% manganese, and 0.05% maximum sulfur) is formed from 10 in. ID, 24 in. OD coil. The channel is pierced, prelanced, daped, blanketed, serrated and lanced. Then a $^{1}/_{16}$ in. diam steel wire hook is preplaced in the $2^{3}/_{8}$ in. long channel, allowing only 0.002 in. tolerance in positioning.

The prebrazed position of the steel hook is maintained by placing the assembly in a specially designed manual work holder that fits into an air-operated clamp, ready for brazing. The brazing filler metal is rapidly built-up in the lanced holes, joining the steel hook to the steel channel. The operator has enough control over the method to form a smooth fill, flush with the top of the channel, eliminating grinding. If any finishing is needed, light brushing or belting removes excess material. Next, the small subassembly is case-hardened at 1600° F oil-quenched and drawn at 550° F to 63–67 Rockwell on the 30 N scale.

The final operation is chrome plating. In a standard operation, chrome is deposited to 0.003 to 0.0005 in. thickness over the entire surface of the unit. Nickel-silver filler metal takes plating equally as well as the steel base metal. No plating problems were encountered.

In a similar operation, a machined block is brazed to the head of a steel channel. In this case the piece is so deep that flux-in-flame operation will not penetrate into the entire brazed area. Application of a

Fig. 1—A liquid flux is metered into the fuel-gas line through the automatic fluxer, shown at the right. Brazing with a nickel-silver alloy eliminates crushing of delicate parts, yet gives high tensile strengths. Together, automatic fluxing and nickel-silver brazing, greatly increased production at Bostitch, Inc.

Fig. 2—Close-up of small steel subassembly shows steel hook brazed into place on upper end of channel. Unfilled lanced hole, lower down on the channel, must be filled flush with the surface. Nickel-silver brazing and automatic fluxing allow close tolerance work and better operator control over deposition than spot and gas tungsten-arc welding

Fig. 3—Subassemblies for large industrial hammer-type staplers are brazed with nickel-silver and automatic fluxing. Tensile strength of the nickel-silver alloy is great enough to withstand prolonged hammering. Overlapping of pieces speeds brazing

small amount of the No. 11 paste flux insures capillary flow to the most hard-to-reach parts.

Spot welding and various other welding methods are still used by Bostitch in assembly stapling-machine chassis. Joseph Kendzia noted a large number of rejects of expensive, machined copper spot-welding tips. Joe designed an additional fixture to the standard tips that eliminated wear on contact surfaces.

An RWMA Class 10 copper-tungsten insert is brazed on the standard electrode at the contact point. Using the No. 11 nickel-silver and jet flux, a bond is formed that will not melt at normal spot-welding electrode temperatures. As the insert wears down, remelting of the nickel-silver allows removal and replacement of the worn insert.

Rejects from worn parts are now eliminated and equipment expenses reduced considerably.

Heavy Plate Girders for Ohio Thruway Welded by Submerged-Arc Techniques

BY PAUL L. HOLDEN

PAUL L. HOLDEN is Field Engineer, The Lincoln Electric Co., Cleveland, Ohio.

All-welded continuous plate girders installed on bridges for the new North-South Ohio Thruway are among the heaviest and largest ever assembled for state turnpike construction. They range up to 144 ft long, 6 ft deep and weighing 22 tons. Fabrication and welding was handled by Builders Structural Steel Corp., Cleveland, followed by rail shipment to the various erection sites.

One installation in Ashtabula County near Kingsville, Ohio, used four 144-ft girders. Shop views of welding operations on these and similar girders are illustrated.

Tractor-mounted full automatic submerged-arc welding equipment of the full automatic submerged-arc type, as well as semiautomatic squirt welders of both manually guided and mechanized types, speeded up welding of web-to-flange joints and of vertical stiffener plates and web and flange splices. Flanges for the long girders varied between $1\frac{1}{4}$ and $1\frac{1}{2}$ in. thick, webs from $\frac{3}{8}$ to $\frac{1}{2}$ in. Stiffeners were $\frac{1}{2}$-in. plate, installed on both sides of the girders except on the outer faces of the outside girders which were left smooth in conformance with conventional highway bridge practice in many states.

Illustrations show the use of the mechanized squirt welder on 80 ft girders with flanges 3 in. thick and webs $1\frac{1}{4}$ in. thick and 44 in. deep. These girders weighed close to 14 tons each. They were placed in the flat or inclined for flat position welding with the mechanically tracked welding gun which laid down $\frac{5}{8}$-in. fillets.

Fig. 1—Mechanized submerged-arc welding gun is being used to attach bracket to web of shorter girder, with flanges 3 in. thick and web $1\frac{1}{4}$ in. Flux and electrode wire feed are automatic as is gun travel

Fig. 2—Girder is tipped 45 deg for squirt welding heavy flange to web with a $\frac{5}{8}$-in. fillet. All the operator needs to do is to guide the welding gun along the joint. Other functions are mechanical from control cabinet at left

Fig. 3—Operator deposits fillet joining $\frac{1}{2}$ in. thick stiffener to girder web. Comparing hand and mechanized submerged-arc welding speeds emphasized the importance of using submerged-arc techniques wherever possible

Society News

Demoret to be Keynote Speaker at Dallas Meeting

Robert B. Demoret

Keynote speaker for the opening session of the 1961 National Fall Meeting will be Robert B. Demoret. He will speak at the opening session as activities officially get underway in Dallas, Tex., at the Hotel Adolphus on the morning of September 25th.

Mr. Demoret is with the Denver Division of The Martin Co. where he is currently Chief of the Astronautics Section which is devoted entirely to design studies of space vehicles and large booster systems. The talk by Mr. Demoret is expected to be both timely and of extreme interest to all AWS members at the Dallas Meeting.

A native of Denver, Colo., Mr. Demoret attended the University of Colorado where he received the degrees of Bachelor and Master of Science in Aeronautical Engineering.

Following his academic studies, he joined the Douglas Aircraft Co. where he worked until 1956, when he joined the Martin Co. At Douglas he was engaged for three years in the aerodynamic design and analysis, wind tunnel testing, and flight testing of surface-to-air and air-to-air missiles.

Later, he directed aerodynamic and performance studies on a wide range of large missiles. These studies encompassed the application of essentially all types of air-breathing and rocket propulsion systems to long range missile missions.

Mr. Demoret is a voluntary consultant for the USAF Air Technical Intelligence Center. He has directed and carried out personally several studies for ATIC, and also was made chairman of the Ballistic Missiles Team of the Engineering Analysis Group on a major project for the Guided Missiles Intelligence Committee.

Welcoming Addresses

Past National President C. I. MacGuffie will call the opening session to order on the Monday morning of September 26th. With the session underway he will then turn the meeting over to National President A. F. Chouinard who will present his opening address with stress on matters of keen importance to all members of the SOCIETY. Individuals following Mr. Chouinard will likewise address the Dallas gathering on behalf of the Atomic Energy Commission Welding

BEFORE ROLLING UP SLEEVES

Arrangements Committee for the 1961 National Fall Meeting in Dallas lunches before getting down to work. Left to right are: National Information-Education Secretary A. L. Phillips, M. Eliot, E. Mai, R. Smith, W. Erwin, F. Salmons, R. F. Skipwith, R. Stewart, V. E. Cresswell, J. E. Dato, National Assistant Secretary F. J. Mooney, and Committee Chairman C. Moss. A. L. Phillips, F. J. Mooney and J. E. Dato were on hand to assist the committee in terms of past experience at other national meetings

Forum, The Welding Research Council, and the Society for Nondestructive Testing. F. W. Davis will represent the AEC Welding Forum while K. H. Koopman will speak on behalf of the WRC. The SNT will be represented by B. E. Justice.

Technical Paper Changes

A noteworthy change has occurred with respect to the Technical Paper Sessions program. The change consists of having another session on Thursday morning, September 28th, when two basic research papers previously scheduled for the preceding Wednesday morning will be presented. The basic research session previously shown as a seminar is now to be a symposium on fundamental research; it will last all day.

The total number of formal technical paper sessions, at which 46 papers will be presented, now totals 15. The presiding officers of each session are recognized throughout the welding industry as being extremely competent in each of their fields. Of the 26 individuals who will preside at the AWS sessions almost one-half are from Texas alone.

Committee Meetings

Beginning Monday afternoon, September 25th, a series of important key committee meetings has been scheduled and will last through Thursday morning, September 28th. These include a meeting of Section officers on Monday afternoon, a member activities committee breakfast meeting on Tuesday morning, education and promotion meetings on Tuesday as well as other meetings throughout Wednesday, including an Ohio State University student alumni dinner on Wednesday evening. The final meeting will be a Board of Directors luncheon on Thursday, September 28th.

Plant Tours

At least two days of plant tours will provide both an unusual and interesting sidelight on some of the principal industries of the region. One such tour will be a trip to Convair in Ft. Worth on the morning of September 26th. Those participating will leave about 8:30 A.M. by bus and return to the city in the early afternoon after reviewing facilities and lunching at Convair.

Events for Ladies

A varied program for ladies includes events on Tuesday and Wednesday. These include a visit to the Museum of Western Art in Ft. Worth which is expected to include luncheon at a well known restaurant. Another highlight of events for ladies only will be a fashion show at the Neiman-Marcus department store on Wednesday afternoon, September 27th. All ladies will thoroughly enjoy the Western Extravaganza which will be held for AWS members, guests, and their ladies at the Austin Patio Ranch on Tuesday evening, September 26th.

Northern New York Plans Welding Course

The education committee of the Northern New York Section, AMERICAN WELDING SOCIETY, will give an eight-week course on welding metallurgy starting October 3rd at Rensselaer Polytechnic Institute, Troy, N. Y. Sessions will be from 7 to 9 P.M. on Tuesdays during the eight-week period.

The subjects covered in this course will be interesting to not only the person who already has metallurgical training but also to the person who is untrained.

The registration fee will be $8.00 for AWS members and $10 for nonmembers.

Persons wishing to obtain further information may write to K. C. Wu, Watervliet Arsenal, Watervliet, N. Y.

Important Notice

The Welding Journal and other AWS departments have moved to the new Engineering Building. All communications should thus be addressed to:

American Welding Society, Inc.
United Engineering Center
345 E. 47th Street
New York 17, N.Y.

Telephone Number: PL 2-6800

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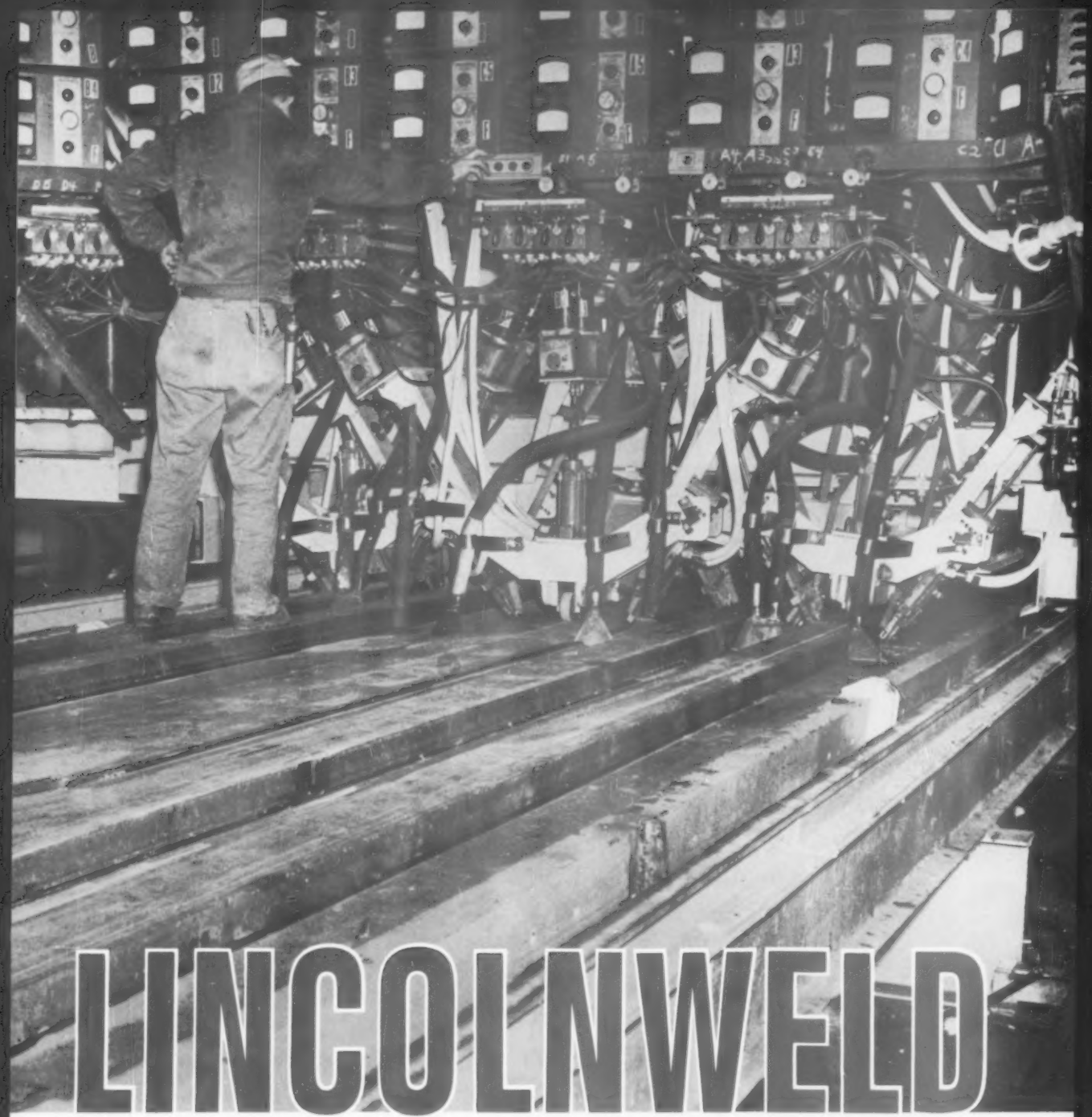


LINCOLNWELD

Here's an expensive, fully automatic submerged arc setup with 16 welding heads. Press the button. Can you count on them all to start perfectly? Every time? This manufacturer can. He chose **Lincolnweld** equipment. Because he knows its welding dependability, ruggedness and easy serviceability will protect his investment and guarantee production by consistently delivering good welds . . . fast . . . at low cost. What is it about **Lincolnweld** equipment that makes these things possible? Why not spend the next few moments reading the answer inside?

These are **LINCOLNWELD** automatic submerged arc welders on the job

Tractor-mounted LAF-3 head welds the giant hull sections of this atomic submarine. After sections are butted together, entire hull is rotated under the unit to complete the 360° weld. New **Lincolnweld** tractor permits use of tandem-mounted heads to get higher speeds, greater efficiency from tractor setup.

LAF-3 head, used for DC welding, lays large fillet on this bridge section at speeds not possible by any other process. Note conveniently mounted controls which let operator govern the process at all times. No involved electronic circuitry to get out of order. Your own shop electricians can keep **Lincolnweld** controls in top operating condition.

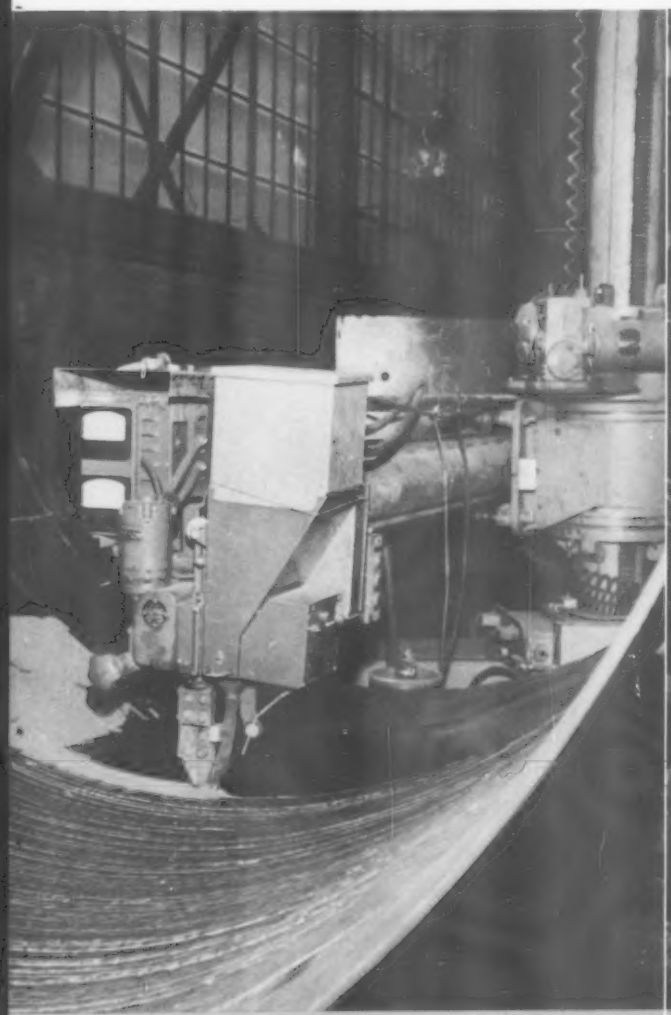
Whether you weld automatically with AC or DC, in the factory or in the field, whether your setup calls for stationary head mounting or travel carriage or tractor, single or double-wire feeds, Lincoln makes equipment to do the job. It's called **Lincolnweld.**

The LAF-3 is for DC, LAF-4 for AC, and LAF-5 for DC welding where there's no 3-phase power source. To get higher speeds or deeper penetration, or to bridge large gaps, any one of these welders can be fitted with two-wire, **Twinarc** heads. Or, they can be mounted in tandem to get very high speeds . . . up to 200 ipm.

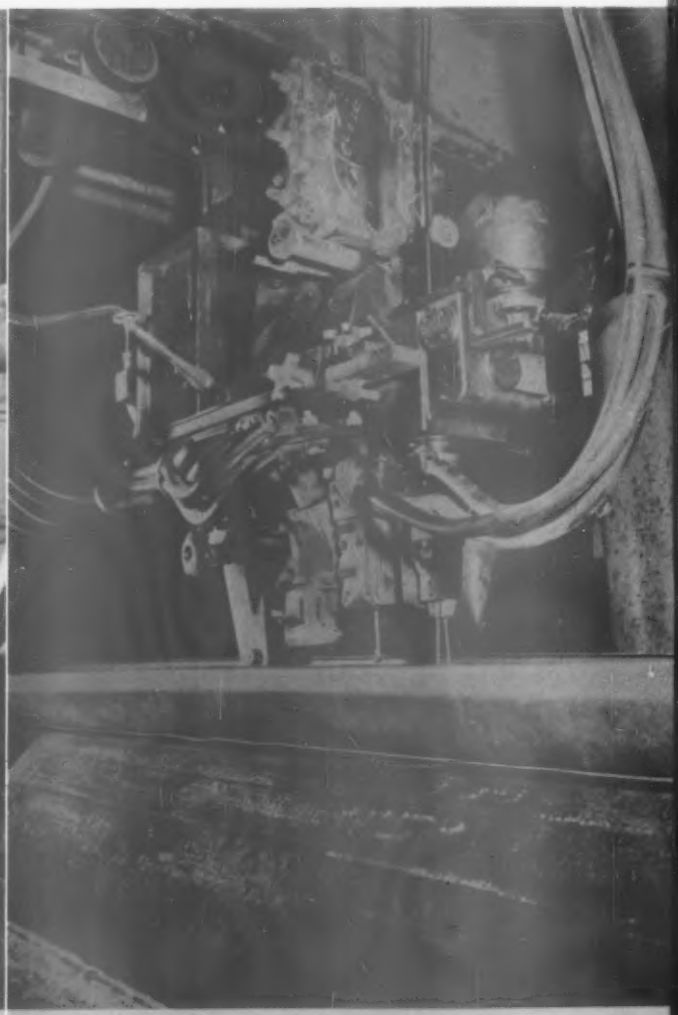
What's more, this equipment is rugged, practical, simple. It ties into existing fixtures easily and its controls integrate easily with the over-all control system. Meters, buttons, controls are all conveniently mounted for work and service. Components are conventional in design. No temperamental electronic equipment to get out of order. Your own electricians can keep this equipment delivering topnotch performance.

LINCOLN WELDERS

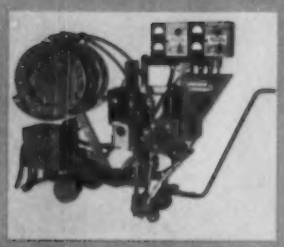
Day-in, day-out welding is rugged. To produce finished parts quickly and at the lowest possible cost, and to protect your investment, use equipment equal to the task . . . **Lincolnweld.** See your Lincoln field engineer . . . a specialist in welding . . . to get all the facts about **Lincolnweld** submerged arc equipment. Ask him for bulletin 5200.1. Or write, The Lincoln Electric Company, Cleveland 17, Ohio.



By hardsurfacing the inside shell of this dust collector, its life was increased six-and-one-half times. Neither high-frequency current nor steel wool balls are needed to start Lincolnweld arc. Just push the button. You get perfect starting every time! And flux flow starts automatically, too, when the arc button is pushed.



Tandem-arc arrangement—two or three heads mounted in tandem—lets you lay down up to three times as much metal as with a single-wire setup. Here, a single 3/16-inch electrode operating on AC is fed in tandem with a DC Twinarc head which simultaneously feeds 2, 1/8-inch electrodes into the work. Setup completes root and cover-pass welds in single pass on heavy locomotive motor frames.



NEW TRACTOR MOUNT FOR LINCOLNWELD EQUIPMENT

BOOM-MOUNTED LINCOLNWELD HEAD

LINCOLNWELD
LAF-3 HEAD
ON CARRIAGE MOUNT

You can count on LINCOLNWELD heads for perfect starts and uniform welds

Lincolnweld equipment is built to deliver reliable performance. It is the only submerged arc equipment which gives consistently perfect starts (without skipping) on low or high-speed welds. The uniformity of its welds hour after hour, day after day, have earned it a reputation envied by all.

Right now there are thousands of **Lincolnweld** units in service laying down metal efficiently, effortlessly. Their users are saving money with every minute of that production time. Perhaps you could benefit by investigating the many ways **Lincolnweld** could be profitably put to work for you.

THE LINCOLN ELECTRIC COMPANY
Dept. WW-21123 Cleveland 17, Ohio
The World's Largest Manufacturer of Arc Welding Equipment and Electrodes

LINCOLN

1961 AWS NATIONAL FALL MEETING

SEPTEMBER 25–28, HOTEL ADOLPHUS, DALLAS, TEX.

REGISTRATION

HOTEL ADOLPHUS

Sunday, Sept. 24 • 3:00 P.M. to 6:00 P.M.
Monday, Sept. 25 • 8:00 A.M. to 4:00 P.M.
Tuesday, Sept. 26 • 8:00 A.M. to 4:00 P.M.
Wednesday, Sept. 27 • 8:30 A.M. to 3:00 P.M.
Thursday, Sept. 28 • 8:30 A.M. to 3:00 P.M.

SEPTEMBER 25, MONDAY MORNING

ROOF GARDEN

10:00 A.M.—Official Opening Session

OPENING ADDRESS

A. F. Chouinard, President, AWS

WELCOME ADDRESSES

F. W. Davis, AEC Welding Forum—K. H. Koopman, Director, WRC—B. E. Justice, SNT

KEYNOTE ADDRESS

Robert B. Demoret, The Martin Co.

SEPTEMBER 25, MONDAY AFTERNOON

THREE SIMULTANEOUS SESSIONS, 2:00 P.M.

Papers "A" Start at 2:00 P.M.
Papers "B" Start at 2:50 P.M.
Papers "C" Start at 3:40 P.M.

1. Ultra High-strength Steels

ROOF GARDEN

Chairman

D. W. Kinsey, U. S. Steel Corp.

Co-Chairman

H. C. Campbell, Arcos Corp.

A. Causes of Microcracking and Microporosity in Ultra High-strength Weld Metal
by Milton D. Randall, R. E. Monroe and P. J. Rieppel, Battelle Memorial Institute

B. Weldability Study of Hot-work Tool Steels
by N. A. Sinclair, and R. P. Sopher, Electric Boat Division, General Dynamics Corp., and J. G. Maciora, Martin Co.

C. Development of High Weld-joint Efficiencies in a Work-hardening Stainless Steel
by William P. Hatch and W. C. Malatesta, Watertown Arsenal Laboratories, and George M. Orner, Manufacturing Laboratories, Inc.

2. Nuclear Components

(Sponsored by AEC Welding Forum)
CACTUS ROOM

Chairman

K. E. Mead, Sandia Corp.

Co-Chairman

F. W. Davis, Southwest Research Institute

A. A Preset Constant Current DC Welding Power Supply
by W. J. Farrell, Sciaky Brothers

B. Development of a Thermoelectric Metal Comparator
by C. C. Stone and D. E. Walker, Argonne National Laboratory

C. Control of Fissuring in Inconel by Regulating Process Variables
by J. D. Carey, General Electric Co.

3. Research and Weldability

DANISH ROOM

Chairman

W. H. Greer, Southwestern Laboratories

Co-Chairman

C. E. Hartbower, Manufacturing Laboratories, Inc.

A. New Developments in Gas Shielding
by Eugene F. Gorman, Linde Co.

B. Welding Nodular Cast Iron Without Post-weld Annealing
by Robert C. Bates and Fred J. Morley, Jr., Westinghouse Electric Corp.

C. Temperature Distribution During Welding of Connections in Concrete Structures
by A. A. Toprac and J. Neils Thompson, University of Texas

SEPTEMBER 26, TUESDAY MORNING

THREE SIMULTANEOUS SESSIONS, 9:30 A.M.

Papers "A" Start at 9:30 A.M.
Papers "B" Start at 10:20 A.M.
Papers "C" Start at 11:10 A.M.

4. Aircraft and Missiles

ROOF GARDEN

Chairman

W. A. Wilson, Geo. C. Marshall Space Flight Center

Co-Chairman

D. B. Howard, ACF Industries, Inc.

A. Fabricating High-temperature Components for Reaction Motors XLR-99 Rocket Engine
by Guido A. Andreano, Thiokol Chemical Corp.

B. Bi-axial Strength of Welds in Heat-treated Sheet Steel
by Donald A. Corrigan, Watertown Arsenal Laboratories, and Roger E. Travis, Victor P. Ardito, and Clyde M. Adams, Jr., MIT

C. Sheet Fracture Toughness Evaluated by Charpy Impact and Slow Bend
by George M. Orner and Carl E. Hartbower, Manufacturing Laboratories, Inc.

5. Nuclear Plant and Cryogenic Materials

CACTUS ROOM

Chairman

J. W. Crosset, International Nickel Co.

Co-Chairman

E. J. Funk, Texas Instruments, Inc.

A. Investigation of Induction Welding for Remote Maintenance
by Arthur L. Lowe, Jr., G. R. Winders and M. Christensen, Babcock & Wilcox Co.

B. The Welding of Beryllium
by R. G. Gilliland and G. M. Slaughter, Oak Ridge National Laboratory

C. An Investigation of the Low-temperature Impact Properties of Stainless Steel Weldments
by H. W. Mishler, Battelle Memorial Institute, and H. J. Nichols, United States Steel Corp.

6. High-strength Low-alloy Steels

DANISH ROOM

Chairman

H. Crick, Mosher Steel Co.

Co-Chairman

S. R. Scales, Hughes Tool Co.

A. Improvement of Low-cycle Fatigue Strength of High-strength Steel Weldments
by M. D. Randall and R. E. Monroe, Battelle Memorial Institute, and H. Fall and D. Brugioni, Caterpillar Tractor Co.

B. Development of Procedures for Welding High-yield Steel
by Clarence E. Jackson, Linde Co., and Larry Robbins, Mare Island Naval Shipyard

C. Study of the Causes of Cracking in Submerged-arc Welds in Constructional Alloy Steels
by M. D. Randall and R. E. Monroe, Battelle Memorial Institute, and H. J. Nichols, United States Steel Corp.

SEPTEMBER 26, TUESDAY AFTERNOON

TWO SIMULTANEOUS SESSIONS, 2:00 P.M.

Papers "A" Start at 2:00 P.M.
Papers "B" Start at 2:50 P.M.
Papers "C" Start at 3:40 P.M.

7. Aircraft and Missiles

ROOF GARDEN

Chairman

E. L. Trimble, Linde Co.

Co-Chairman

A. A. Stiles, Chance Vought Co.

A. High-quality Aluminum Gas-metal-arc-spot Welding for Launch Space Vehicle Applications
by Daniel M. Daley, Jr., W. M. McCampbell and J. C. McCaig, Redstone Arsenal

B. Superalloy Multilayer Sandwich Structures for Application to 1800° F
by Harold Smallen, Norair Division, Northrop Corp.

C. Welding Evaluation of High-temperature Sheet Materials by Restrained Patch Testing
by Stanley Weiss, W. P. Hughes and H. J. Macke, General Electric Co.

8. Shop Practice

DANISH ROOM

Chairman

M. E. Eliot, Mosher Steel Co.

Co-Chairman

L. D. Sugg, Air Reduction Sales Co.

A. Welding Keeps Oil Refinery Mechanical Equipment Operating
by Ray M. Kolb, American Oil Co.

B. Hose for Oxygen Cutting Processes
by Paul Hopkins, Electric Hose and Rubber Co., and E. Meincke, Linde Co., for the Hose Technical Committee of the Rubber Manufacturer's Association

C. How Specifications Influence Gas Pressure Regulator Design
by Byron H. Acomb, Linde Co.

SEPTEMBER 27, WEDNESDAY MORNING THREE SIMULTANEOUS SESSIONS, 9:30 A.M.

Papers "A" Start at 9:30 A.M.
Papers "B" Start at 10:20 A.M.
Papers "C" Start at 11:10 A.M.

9. Electron Beam Welding

ROOF GARDEN

Chairman

F. W. Hussey, Frankford Arsenal

Co-Chairman

P. J. Rieppel, Battelle Memorial Institute

A. Characteristics and Strength Data of Electron Beam Welds in Four Representative Materials
by Robert E. Roth and Nick F. Bratkovich, Allison Division, General Motors Corp.

B and C. A Study of Electron Beam Welding
by S. S. White, H. J. Lander, W. T. Hess, R. Bakish and McD. Schetky, Alloyd Electronic Corp.

10. Nondestructive Testing

(Sponsored by SNT)

CACTUS ROOM

Chairman

J. H. Hunt, Combustion Engineering, Inc.

Co-Chairman

G. Farrer, Babcock & Wilcox Co.

A. Nondestructive Testing in Utilities, Commercial, Nuclear Steam Generating Equipment
by William Bunn and E. S. Proctor, Combustion Engineering, Inc.

B. Maintenance Inspection of Welds and Materials in Service
by Dwight J. Evans, Engineering Test Service, Inc.

C. Preparation of Materials—Interpass and Final Inspection of Welding in the Fabrication of Pressure Vessels and Submarine Hulls
by Thomas J. Dawson, Ingalls Shipbuilding Corp.

11A. Symposium on Fundamental Research

DANISH ROOM

(Sponsored by University Research Committee of WRC)

Chairman

R. K. Grier, Allied Research Associates

Co-Chairman

C. M. Adams, MIT

9:30 A.M. Introductory Remarks (A. R. Lytle, Linde Co.)

9:45 A.M. Panel Discussion: Heat Transfer Intensity of Electric Arcs. (Speakers: W. J. Greene, Air Reduction Co.; O. H. Nestor, Linde Co.)

11:30 A.M. Panel Discussion: Transient Heat Flow. (Speakers: L. Tall, Lehigh University; T. Goodman, Allied Research Associates, Inc.; J. Eckert, University of Minnesota.

SEPTEMBER 27, WEDNESDAY AFTERNOON TWO SIMULTANEOUS SESSIONS, 2:00 P.M.

Papers "A" Start at 2:00 P.M.
Papers "B" Start at 2:50 P.M.
Papers "C" Start at 3:40 P.M.

11B. Symposium on Fundamental Research

DANISH ROOM

(Sponsored by University Research Committee of WRC)

Chairman

R. K. Grier, Allied Research Associates

Co-Chairman

C. M. Adams, MIT

Continuation of Session 11A.

2:00 P.M. Panel Discussion: Thermal Stresses (Speakers: C. M. Adams MIT; W. F. Savage, RPI; D. Rosenthal, University of California

12. Applications

ROOF GARDEN

Chairman

I. D. Holster, Air Reduction Sales Co.

Co-Chairman

V. E. Cresswell, Independent Welding Supply Co.

A. Magnetic-flux Gas-shielded Arc Welding on Boiler Fabrication
by Frank W. Armstrong, Babcock & Wilcox Co.

B. Plasma-arc Welding Surfacing
by Robert S. Zuchowski, Linde Co., and Russell Culbertson, Haynes Stellite Co.

C. Gas Metal-arc Welding Aluminum with Large Diameter Fillers
by James A. Liptak, Kaiser Aluminum & Chemical Corp.

SEPTEMBER 28, THURSDAY MORNING

THREE SIMULTANEOUS SESSIONS, 9:30 A.M.

Papers "A" Start at 9:30 A.M.
Papers "B" Start at 10:20 A.M.
Papers "C" Start at 11:10 A.M.

13. Special Processes

ROOF GARDEN

Chairman

A. E. Wisler, Hughes Tool Co.

Co-Chairman

D. C Ransone, Linde Co.

A. Properties of Friction Welding Plain-carbon and Low-alloy Steels
by Thomas H. Hazlett, University of California

B. Electromagnetic Stirring of Arc Welds
by David C. Brown, Frank A. Crossley, John F. Rudy and Harry Schwartzbart, Armour Research Foundation of Illinois Institute of Technology

C. Applying All the Rules of Resistance Welding with Automatic Control
by Charles F. Paxton and Richard S. Zeller, Weltronic Co.

14. Pressure Vessels and Heat Exchangers

DANISH ROOM

Chairman

C. W. Wheatley, A. O. Smith Corp.

Co-Chairman

J. Earthman, Wyatt Metal and Boiler Works

A. Corrugated Monel Heat Exchanger
by J. F. O'Connell, N. J. Ritchey and J. C. Stewart, The J. B. Beaird Co.

B. Properties and Fabrication of High Strength 2¼% Chromium—1% Molybdenum Materials
by Robert C. Griffin and George N. Emmanuel, Babcock & Wilcox Co.

C. Accelerated Cooling of Carbon Steels for Pressure Vessels
by Domenic A. Canonico, Edward H. Kottcamp and Robert D. Stout, Lehigh University

15. Basic Research

CACTUS ROOM

Chairman

W. B. Bunn, Combustion Engineering Inc

Co-Chairman

M. L. Begeman, University of Texas

A. Residual Stresses in Welded Plates—A Theoretical Study
by Lambert Tall, Fritz Engineering Laboratory, Lehigh University

B. The Effect of Plate Thickness and Radiation on Heat Flow in Welding and Cutting
by Pravin Jhaveri, W. G. Moffatt and Clyde M. Adams, Jr., MIT

SEPTEMBER 28, THURSDAY AFTERNOON

TWO SIMULTANEOUS SESSIONS, 2:00 P.M.

Papers "A" Start at 2:00 P.M.
Papers "B" Start at 2:50 P.M.
Papers "C" Start at 3:40 P.M.

16. Titanium and Beryllium

DANISH ROOM

Chairman

H. Schwartzbart, Armour Research Foundation

Co-Chairman

G. R. Rothschild, Air Reduction Sales Co.

A. The Welding of Titanium to Steel
by D. R. Mitchell, Titanium Metals Corp. of America

B. Welding of 2-in. Thick Titanium-alloy Plate
by R. L. Koppenhofer, W. J. Lewis, G. E. Faulkner, and P. J. Rieppel, Battelle Memorial Institute

C. Diffusion-bonding High-temperature-alloys with Beryllium
by William Feduska and Walter L. Horigan, Westinghouse Electric Corp.

17. Piping

ROOF GARDEN

Chairman

A. G. Barkow, Natural Gas Pipeline Co. of America

Co-Chairman

A. J. Shoup, Texas Eastern Transmission Corp.

A. Automatic "Stove Pipe" Welding Comes to the Pipe Lines
by Howard B. Cary, Hobart Brothers Co., W. B. Handwerk, Crose-Perrault Equipment Corp., and B. K. Elliott, H. C. Price Co.

B. An Automatic CO_2-shielded Welding Process for Double-jointing Pipe
by J. W. Nelson, Glenn E. Faulkner and P. J. Rieppel, Battelle Memorial Institute

C. Automatic Welding of Transmission Line Pipe
by Roger W. Tuthill, Air Reduction Sales Co.

Other Activities at Hotel Adolphus, Dallas, Texas

MONDAY, SEPTEMBER 25

2:00 P.M.—Section Officers' Meeting

TUESDAY, SEPTEMBER 26

8:00 A.M.—Membership Activities Committee Breakfast Meeting
9:15 A.M.—Educational Open Meeting
2:00 P.M.—Promotion Open Meeting
5:00 P.M.—"Western Extravaganza" Barbecue

WEDNESDAY, SEPTEMBER 27

9:00 A.M.—Missiles and Rockets Welded Fabrication Committee Meeting
10:00 A.M.—Publications and Promotions Council Meeting
10:00 A.M.—Technical Council Meeting
2:00 P.M.—Districts Council Meeting
7:00 P.M.—Ohio State University Student Alumni Dinner

THURSDAY, SEPTEMBER 28

10:00 A.M.—Board of Directors Meeting
12:30 P.M.—Board of Directors Luncheon

Combined Plant Tours

WEDNESDAY, SEPTEMBER 27

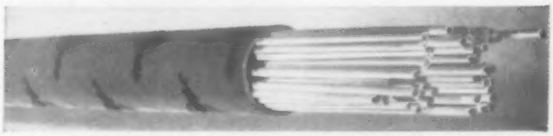
General Dynamics, Fort Worth Plant (B-58 airplane production)

Mayhew Machine Plant, Div. of Gardner-Denver Co. (Dallas)

Leave: 8:30 A.M. Return: 4:00 P.M.
Cost: $5 per person
Includes 2 plants, lunch and transportation

3 METHODS OF PRODUCTION BRAZING ...Which is best for you?

FLUX COATED ROD



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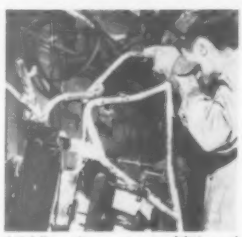
BARE ROD AND FLUX



Welding time was cut 25% and clean-up time 75% by using All-State nickel-silver and separate flux when brazing 1" mild steel tubing in power saw frame production.

For the occasional job or where brazing operations change from time to time, ALL-STATE suggests that bare bronze with #41 or #1 flux is the most flexible method, providing maximum control of capillary flow. Recommended for deep joints.

Nickel-silver rod with #11 flux is a versatile combination for joining dissimilar metals. TS up to 80,000 psi.

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View of the United Engineering Center from the Beekman Tower Hotel shows its location on the New York scene with other familiar skyscrapers. Most of the engineering societies, including AWS, housed in the old Engineer's Building on W. 39th St., will be moving to the new location during September

Engineers' New Headquarters

Moving day is at hand for the AMERICAN WELDING SOCIETY's Headquarters Staff. Some 38 persons will have everything from desks to paperclips moved to bright, cheerful surroundings on the eighth floor of the United Engineering Center at 345 E. 47th St., New York City. The new building has the added facilities of an employe cafeteria and an exhibit hall.

UNITED ENGINEERING CENTER

Honor Sections

Section	Goal, %	Section	Goal, %
Oklahoma City	138	Niagara Frontier	107
New Jersey	133	Sangamon Valley	107
Louisville	130	Maryland	106
Mahoning Valley	121	Bridgeport	105
Kansas City	120	San Antonio	105
Worcester	120	Syracuse	105
Baton Rouge	119	Cincinnati	104
Birmingham	118	Providence	104
Northwest	117	Northern N. Y.	103
North Texas	115	Chicago	102
Hartford	114	N. E. Tennessee	102
Wichita	113	Puget Sound	102
Philadelphia	112	Saginaw Valley	102
Colorado	111	Tulsa	102
Detroit	111	San Diego	101
Albuquerque	110	Chattanooga	100
Dayton	110	Eastern Illinois	100
New Hampshire	110	Long Beach	100
Pascagoula	110	Los Angeles	100
Richmond	110	Madison-Beloit	100
Western Mass.	110	Michiana	100
Holston Valley	109	Mobile	100
New York	109	Nashville	100
Rochester	109	N. Central Ohio	100
St. Louis	109	Olean-Bradford	100
Boston	108	Salt Lake City	100
Long Island	108	San Francisco	100
Toledo	108	Santa Clara Valley	100
Iowa	107		

Pledges Needed to Meet Goal

Section	Needed	Section	Needed
Pittsburgh	25	New Orleans	350
Carolina	64	Peoria	365
Anthony Wayne	150	Susquehanna Valley	350
Shreveport	155	York-Central Pa.	375
Iowa-Illinois	180	Portland	385
Washington	180	Houston	400
Arizona	200	Sabine	400
Nebraska	200	Lehigh Valley	415
J. A. K.	275	Fox Valley	450
Orange County	275	Stark Central	495
Northwestern Pa.	280	Columbus	770
Indiana	312	Milwaukee	877
South Florida	330	Cleveland	900
Western Michigan	330		

Pledges continue to move sections up the ladder to reach their goal. The majority of sections have attained 100% or more of their assigned quotas and have been placed on the Honor Roll. The last count shows AMERICAN WELDING SOCIETY pledges to be at 91% of goal.

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2. Enables operator to maintain uniform quality in brazing operation.
3. Allows alloy to be placed internally to flow outward to joint boundaries—aids in obtaining positive filling of the joint and a quick visual inspection for quality.
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KEEPING YOU POSTED

By Fred L. Plummer

● The writer of these notes, which appear each month under the "Keeping You Posted" title, has been repeatedly amazed and pleased by the surprisingly large number of WELDING JOURNAL readers who have indicated that they regularly read and enjoy this section of the magazine. These readers may be interested to learn that the first installment was published in the August 1957 issue of THE WELDING JOURNAL, that this installment is the fiftieth in the series and that the total number of words is well over 100,000—the equivalent of an average length novel.

● During the past four years national activities of the SOCIETY—JOURNAL, Technical, HANDBOOK, Education, Information, Meetings, Exposition, International, Membership Services—as measured by income and expense, have increased by more than fifty percent. Income and expense for the 1956–57 fiscal year were each slightly less than $500,000. During the next four fiscal years, income equalled $564,000, $600,000, $680,000 and $713,000. Corresponding expenses averaged $11,000 less than income for each year. Our budget for 1961–62 provides for an income of $768,000.

During these same four years there has been no significant change in membership, which has totaled between 12,000 and 13,000. Assistant Secretary Mooney and National Membership Chairman Axtell are heading a drive which should soon result in a total membership of at least 14,000. The total number of headquarters staff employees is now 38, an increase of only eight during the past four years.

● These notes will be published in the September 1961 issue of the WELDING JOURNAL which will be delivered to readers a few days after our headquarters have been moved to the eighth floor of the new United Engineering Center at 345 E. 47th St., New York 17. As of mid-July all five of the founder societies have pledged more than their quotas (varying from $300,000 to $900,000) to the UEC Building Fund. AWS pledges equal 90 percent of quota, fifty-six Sections having met or exceeded their quotas. Several other Sections expect to meet their quotas soon.

● During September, Dallas and Fort Worth become the center of AWS activities as hundreds of AWS members gather there, together with representatives of the AEC Welding Forum, the Welding Research Council and the Society for Nondestructive Testing, for our National Fall Meeting. Director Cliff Moss and Representatives of the North Texas Section are planning special events in keeping with Texas traditions. Don't miss the high quality technical program, the keynote addresses, outstanding plant tours, ladies' program and special events.

● Last June 1st a special subcommittee authorized by our Manufacturers' Committee to study factors which affect the frequency, size and location of and attendance at our Welding Expositions, met in your Secretary's office and prepared a factual report which has been submitted, together with a questionnaire, to exhibitors at recent Welding Expositions. Past-President C. I. MacGuffie is chairman of this group which includes R. T. Brown, J. J. Dall, G. E. Kemper, T. S. Long and J. E. Norcross.

● The following day your Secretary recorded a sound tract for a 15 minute movie which shows exhibits and events at the 1961 Welding Exposition held in the New York Coliseum April 18–20. This film will be available for use at Section meetings during the current fiscal year. It provides an excellent review of this most successful welding show.

● National officers of AWS spent June 5th and 6th in New York at meetings of the Executive-Finance Committee and the Board of Directors. Principal items of business were the establishing of a balanced budget of income and expense and the approval of staff and committee personnel for our 1961–62 fiscal year. Other matters considered at these meetings included approval of formation of the AWS Hawaii Section, selection of names of individuals to be recommended to USA President as possible appointees to the National Science Board, authorizing the AWS Committee on Brazing and Soldering to conduct a special research project concerning the use of filler metals containing cadmium, receiving the acceptance by R. E. Lorentz of the invitation to present the 1962 Adams Lecture on April 9th in Cleveland, and consideration of final plans for the National Fall Meeting in Dallas. President A. F. Chouinard presided at both meetings.

● On June 7th the American Rocket Society held a special luncheon for society executives and representatives of the press as preview for the large assembly and exposition "Space Flight Report to the Nation" to be held in New York, October 9–13.

● Assistant Secretary F. J. Mooney visited Detroit during June 8th and 9th for meetings of the National Association of Exhibit Managers. This group includes representatives of most societies, institutes and associations which sponsor major exhibits.

● The Department of Welding Engineering at Ohio State University with Director Roy B. McCauley as Chairman, conducted an important Summer Conference Course in the Fundamentals of Welding Engineering during the period June 12–23. Professor McCauley, Dr. Robert C. McMaster and Instructor William L. Green supervised the course and served as instructors.

● Vice-presidents C. E. Jackson and J. Bland visited headquarters on June 19th for conferences with various staff members concerning special Society projects.

● Exposition Committee Chairman J. E. Norcross presided at a meeting of this group held in your Secretary's office June 21th. The financial report for the New York Exposition was reviewed, and a budget and management proposal

for the 1962 Cleveland Exposition were approved. The theme for the Cleveland Show will be "Better Products Through Welding." A special welded-products theme-exhibit will be sponsored by AWS to emphasize the tremendous range of products for which economical fabrication depends upon welding. The Cleveland Show will be co-sponsored by the Society for Nondestructive Testing and will include more exhibits of testing and inspecting equipment.

● Your Secretary traveled to Troy, Ohio, on June 22th to participate in the three day "Summit Meeting" organized by The Hobart Brothers Co. for the benefit of their distributors. General Chairman W. B. Howell was master-of-ceremonies at the banquet and AWS Director W. H. Hobart, Jr., was moderator for a panel discussion on "The Outlook for the Arc Welding Industry over the Next Ten Years" during which your Secretary spoke about "Processes that will Compete with Arc Welding," covering laminated wood construction, plastics, high tension bolts and especially precast and prestressed reinforced concrete construction. Director Roy B. McCauley, former Section Chairmen L. C. Monroe of Chicago and T. L. Dempsey of Cleveland, and Publisher T. B. Jefferson also took part in this discussion. Your Secretary thoroughly enjoyed the privilege of being house guest of Vice-president J. H. Blankenbuehler and his family.

● Director George Bland opened the meeting of District 8 Section Officers held in Denver, July 1. C. Brinton Swift reports that, following an all day meeting, representatives of the Kansas City, St. Louis, Northwest and Colorado Sections, with their wives, enjoyed a mountain tour and a fine steak dinner at Greystone Ranch.

● The Executive Committee of TAC held an all day meeting at Headquarters on July 10th with Chairman J. J. MacKinney, Vice-chairman F. W. Hussey and Secretary E. A. Fenton in charge. Technical Council Chairman J. H. Blankenbuehler also attended this meeting at which important standards, reports, procedures and committee appointments were discussed and approved or rejected.

● The following day Chairman R. E. Lawson presided at an all day meeting of the Publicity Committee with Secretary A. L. Phillips, M. D. Bellware, W. H. Hobart, Jr., and F. X. Neary in attendance. Plans for the "publicity workshop" program to be held at the Dallas Fall Meeting for Section Publicity Chairmen, for the promotion of 1962 National Welded Products Month and for publicizing the 1962 Annual Meeting and Welding Exposition were discussed and finalized. Much time was devoted to the discussion and development of plans for the special welded-products theme-exhibit which will be a new feature of the 1962 Welding Exposition.

● That same evening Convention Manager F. J. Mooney, Publicity Manager A. L. Phillips, Exposition Manager R. T. Kenworthy and your Secretary flew to Cleveland for conferences the next day with representatives of the Exposition Hall, Convention Bureau, Press Club and Hotel Sheraton-Cleveland, and with the Board of Directors and Convention Arrangements Committee of the Cleveland Section. Wasil R. Romance is Chairman and Jenine Darbyshire is Secretary of the Section. Anthony S. Graskey will serve as Chairman of the Cleveland Arrangements Committee for the 1962 Annual Meeting. It is expected that the Annual Symposium of the Cleveland Section, normally held on the second Friday of May will be held next year on April 9th as a special feature of the Annual Meeting.

● Vice-president C. E. Jackson will address the Australian Institute of Welding at their annual meeting early in September. Following a tour of Australia with several additional speaking engagements, he will return via Honolulu where he will probably meet with our newest AWS Section about October 2nd.

● A recent report from W. R. Smith outlines the following outstanding accomplishments of the Santa Clara Section during the 1960–61 fiscal year: (1) the biennial welding show, (2) presenting four scholarship awards to students attending U.C., Stanford and Cal-Poly, (3) distributing at Section's expense 1000 copies of "Opportunities in the Welding Industry," (4) the annual Spring Lecture Series at San Jose State College and (5) pledging the full Section quota to the UEC Building Fund.

AWS
NATIONAL FALL MEETING
September 25–28
Hotel Adolphus, Dallas, Texas

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Welding Contributions to Each Generation

BY LESLIE E. WAGNER

Colonial Days

Welding in the form of blacksmith forging was used by the colonial people at an early period in the history of the United States. Among the early immigrants were craftsmen of various trades including iron workers and blacksmiths from the iron industry of their home lands. Iron ore in the form of bog iron was found in the swamps and river beds in sufficient quantities to encourage the establishment of iron making, with furnaces patterned after the European furnaces.

By 1643, iron ore had been discovered in quantity and English financiers found iron works at areas known as Saugus and Braintree, Mass. Scot laborers, prisoners of the English Civil War, were brought to Massachusetts to work in these iron works.

An iron producing furnace called a "bloomery" was constructed. The iron ore was melted by burning wood and a puddle iron or pig iron was produced. The iron workers made this pig iron into bars, using water power to operate the heavy hammers.

The blacksmiths used the bars to make tools, home appliances; anchors for the ships; welded chains and other important articles.

The Saugus Works served for many years and has recently been rebuilt by the present-day steel industries. It is today a tourist attraction and a memorial to America's first industry.

Still another fortunate discovery made by the colonial people was the finding of a good bituminous coal, free of sulfur. This aided the smith in producing a slag-free welded joint.

Among the many welding contributions the smithy made to colonial progress are: (*a*) The welding of the eye of the axe that was used to cut the logs for the log cabins which sheltered the families and opened up the forest land for the food crops; (*b*) Welded chains which served many purposes, and (*c*) Shanks welded to agricultural tools to accommodate wood handles. Fig. 1 illustrates a typical blacksmith shop.

Fig. 1—Old time blacksmith's shop

Westward Movement

The Westward Movement was the expansion period in which many hundreds of families began a western trek over the Appalachian Mountains seeking better lands for homesteading. Welding played a significant part in the successful accomplishment of the journey to the west.

Fig. 2—Iron band was formed, welded and shrunk on a wagon wheel

The iron band illustrated in Fig. 2 which was formed, welded and shrunk on the wood felloe of the wagon wheel by the skilled blacksmith made the difference between success and failure of these expeditions. No wood felloe alone could possibly have traversed the rough country. Many other parts of the wagon were welded but this one illustration alone will prove the value and contribution of welding to these early generations who played so great a part in the development of our nation.

Framed Building Era

Families soon outgrew the log cabin and larger homes were needed to accommodate the increasing size of the families. Welding again made its contribution to progress.

The broad axe was employed in shaping the logs into rectangular timbers for the frames of the build-

LESLIE E. WAGNER is Assistant Professor of Welding, Department of Mechanical Engineering, College of Engineering, University of Michigan, Ann Arbor, Mich.

ings. The eye of the hewing axe was made of mild steel welded to a tool steel blade, thereby giving a keen cutting edge for hewing and a soft steel for absorbing the shock,

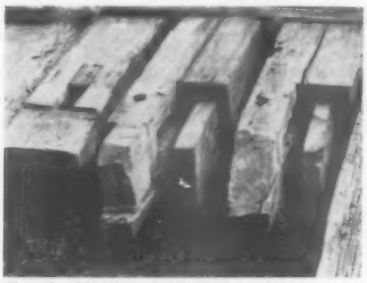

Fig. 3—Mortise and tenon joints produced by hand

preventing fatigue failure of the steel eye. The mortise and tenon joints (Fig. 3) on the frames were made possible by a wood chisel (Fig. 4) which was produced by welding a low carbon shank to a higher carbon steel blade, with provision for a wood handle, which absorbed the mallet blow.

The Horseless Carriage Days

The first automobile bodies and frames were joined together by rivets and bolts which always were a

Fig. 4—Wood chisel consisting of a low-carbon shank welded to a higher-carbon steel blade

source of annoyance by their squeaks and rattles. The body frames of the early models were constructed of wood covered by metal usually having a canvas top. In case of accidents the wood splintered seriously injuring the passengers. A new type of welding, known as resistance welding, was introduced replacing the fusion blacksmith welding.

Today millions of beautiful streamlined automobiles coming off production lines are all-welded steel structures with over eight thousand spot welds making a very rigid, safe mode of transportation.

Welded steel structures are replacing the riveted frames in the form of bridges, buildings, etc.

Ships that sail the seas have experienced cycles of various types of construction from wood frames, riveted steel structures to all-welded hulls and super decks. The majority of home appliances of today are all-welded structures displaying a smooth, neat appearance.

Modern Welding Engineering

Welding has contributed tremendously to the development of air travel. The first airplane was constructed of wood frames with open cockpits. Next came the all riveted fuselage and wings which caused wind resistance and reduced flying speeds. Today, the airplane is completely redesigned using an all-welded aluminum skin, and traveling at speeds faster than sound. The all-welded diesel engine has replaced the steam locomotive and many other railroad changes have been made to increase the efficiency of rail travel.

Missile Age

A new era is coming into existence known as the missile age where man is sending objects into the solar areas and stratosphere exploring outer space, something unheard of a few years ago. Welding has made this possible by developing processes and techniques with which to fabricate the structures and components which can withstand the tremendous strains involved.

Summary

Today welding has grown from the one process—forge welding—to thirty-eight or more different joining processes. Many of these operate semi- or fully automatically, joining very thin or very large thick sections of metal together. Numerous kinds of metals are welded today in contrast to the welding of a single metal— iron—in colonial days.

Welding in one form or another has played an important part in aiding and shaping the destiny of the American people from the colonial periods to the present time.

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SECTION NEWS AND EVENTS

As reported to Catherine M. O'Leary

California

ANNUAL LADIES' NIGHT

Sunnyvale—The Annual ladies' night and the installation of officers meeting of the *Santa Clara Valley* Section was held at the Jamaica Inn on the evening of June 3rd.

Members and their wives and guests enjoyed an hour and a half of visiting and getting acquainted before dinner. During the dinner Mrs. W. R. Smith, wife of the retiring Section Chairman, was presented with a white orchid corsage in appreciation of her cooperation during the past season.

An annual report was presented by Section Secretary W. C. Schultz. This was followed by drawings for door prizes obtained by the Arrangement Committee. During the evening, a silver bowl was presented to Arnold Otto, chairman of the committee for the Third S.C.V Section Welding Show. This award was presented in appreciation of a fine job of organizing and conducting the two-year activity that was finished in October 1960.

A past-chairman pin was given to retiring Chairman W. R. Smith in appreciation of a job well done during his term of office.

The remainder of the evening was spent in dancing and friendly sociability.

NEW CHAIRMAN

R. C. Bertossa who was installed as chairman of the Santa Clara Valley Section at the Annual Ladies' Night June 3rd

SECTION MEETING CALENDAR

SEPTEMBER 5

AUSTIN Division. "Welding Procedures," Hubert Crick, Mosher Steel Co.

SEPTEMBER 8

DETROIT Section. G. N. Sieger Award dinner meeting. Ford Motor Co., Central Office Bldg. Dinner 6:30. Meeting 8:00 P.M.

SEPTEMBER 11

SAN ANTONIO Section. "Welding of Low Alloy and Stainless Steel and Related Electrode Use," W. H. McGrew, Air Reduction Sales Co.

SEPTEMBER 12

COLORADO Section. Denver. "Treatment and Fabrication of Heated and Quenched Alloy Steels."

TULSA Section. Plant tour of Dewey Portland Cement Co., Tulsa, Okla., 8:00 P.M. Dinner at Bordon's Cafeteria in Sheridan Village 6:30 P.M.

SEPTEMBER 14

CHICAGO Section. Calumet meeting. Vogel's Restaurant, Social 5: 30, Dinner 6:30, Meeting 7:45 P.M. "New Developments in Welding Field Transmission Lines," R. A. Stone, Airco.

NORTH TEXAS Section. Amon Carter Field. Dinner and technical session, 6:30 P.M. "Carbon-Dioxide Welding," A. O. Smith and General Dynamics.

SEPTEMBER 15

LONG BEACH Section. Long Beach, Calif.

SEPTEMBER 19

HARTFORD Section. Plant tour: Pratt & Whitney Aircraft. Dinner at Villa Maria Restaurant.

NEW JERSEY Section. Essex House, Newark, N.J. Dinner 6:30; Meeting 8:00 P.M.

SEPTEMBER 20

HOUSTON Section. "Welding Code Pressure Vessels," Roy Lorentz, Jr., Combustion Engineering Inc.

TOLEDO Section. Plant visit: Sun Oil Company. Dinner at Toledo Yacht Club 6:30 P.M.

SEPTEMBER 21

CHICAGO Section. Fourth Annual Educational Lecture Series: Welding Processes. First Session: "Manual Metal Arc," W. B. Blackburn, International Harvester Co., Chicago Bridge & Iron Co. Dome.

KANSAS CITY Section. Kansas City, Mo., "Plasmarc Processes," J. E. Dato, Linde Co.

NASHVILLE Section. Open house at J & L Warehouse, Nashville, Tenn.

SABINE Section. "Welding Code Pressure Vessels, Roy Lorentz, Jr., Combustion Engineering Inc.

STARK CENTRAL Section. Red Coachman, Canton, Ohio. "Natural Gas Cutting" G. R. Spies, Airco.

SEPTEMBER 26

SANTA CLARA VALLEY Section. Sabella's Restaurant, Sunnyvale, Calif. 7:00 P.M. "Aluminum Brazing," R. B. Eckenstein, Air Research Mfg. Co.

SEPTEMBER 28

CHICAGO Section. Fourth Annual Educational Lecture Series: Welding Processes. Second Session: "Metal Cutting," W. K. Johnson and J. T. Ryerson, Chicago Bridge & Iron Co. Dome.

OCTOBER 3

TULSA Section. "Progress Report on the Flux-Cored CO_2 Process" A. F. Chouinard, National Cylinder Gas Div., Chemetron Corp.

OCTOBER 4

SUSQUEHANNA VALLEY Section. Foothills Manor, Shickshinny, Pa. Dinner 6:30. "Structural Welding: Design, Materials and Procedures" LaM. Grover, Air Reduction Sales Co.

Editor's Note: Notices for December 1961 meetings must reach JOURNAL office prior to September 20th so that they may be published in the November Calendar. Give full information concerning time, place, topic and speaker for each meeting.

Indiana

PERCUSSION WELDING

Cumberland—Twenty-six members of the *Indiana* Section attended the May 26th meeting held at Buckley's Restaurant. Guest speakers were Eric Heider and Jerry Welch, welding engineers for Cutler Hammer Co. They discussed "Percussive Welding and its

ANOTHER GOVERNOR

Connecticut was a fifth state to proclaim National Welded Products Month in April. Left to right are: Chairman H. A. McGlew of the Hartford Section, Vice-chairman F. J. Wallace, Governor Dempsey of Connecticut and Second Vice-chairman J. O. Wiswell

Applications." Their presentation covered the welding of various types of relay contacts and terminals in a variety of metals with different electrical conductivity and melting temperatures. They described a magnetic force resistance welder which they had designed and built. This machine provided the necessary synchronization of the force and current to produce an improved weld nugget at the contact to terminal junction. Actual terminal components of various sizes and shapes were shown to illustrate the application of percussion welding in the manufacture of relays.

Iowa

WELDING FASTENERS

Des Moines—G. F. Grey, chief engineer for the Ohio Nut & Bolt Co., Berea, Ohio, was guest speaker at the April 20th meeting of the *Iowa* Section. His talk on "Fasteners for Resistance Welding" covered all kinds and sizes of fasteners of interest to all types of fabricators. Mr. Grey has a wealth of experience in his subject, holding a number of patents on weld fasteners as well as on the electrodes used for welding them.

Michigan

ANNUAL LADIES' NIGHT

Detroit—Over 800 guests enjoyed a floor show as well as an excellent dinner and many fine door prizes during the Annual Ladies' Night Party of the *Detroit* Section on May 20th at the Latin Quarter.

RECOGNITION FOR A PAST CHAIRMAN

Chairman Al Lindsey awards past chairman pin to Art Brown at Detroit Section meeting on June 1st

FOLLOW THE LEADERS...

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For details, circle No. 15 on Reader Information Card

NEW CHAIRMAN

Detroit—On the evening of June 1st, officers and Executive Committee members of the Detroit Section for the coming year enjoyed a very fine dinner and meeting.

The committee, consisting of 30 very active members, was enthusiastic in its praise of retiring chairman, Art Brown, for a very successful year.

After installing the new chairman, Al Lindsey, and his officers, assignments were made to the various committee members and a preliminary program was outlined for the coming year.

New York

INDUSTRIAL RADIOGRAPHY

Buffalo—At the last meeting of the season on May 25th, retiring chairman William L. Burch turned the gavel of the *Niagara Frontier* Section over to incoming chairman, James J. Russ. The other new officers are First Vice-chairman—Robert J. Saxton, Jr., Second Vice-chairman—Jerry J. Wright and Secretary - Treasurer — Robert Siemer.

The speaker for the evening was Ralph Turner of Eastman Kodak Co. Mr. Turner discussed" Industrial Radiography" and showed excellent color slides on principles and unusual applications such as inspection of wheat grains for bug infestation. In regard to sources, he said that isotopes have advantages over X-rays; these advantages include portability, low maintenance, a known and constant type of radiation and almost unlimited power. This power (one-half to one million volts) is useful for heavy materials but, at the same time, constitutes the biggest disadvantage of the isotope source since it cannot be "throttled down" to provide good sensitivity on thin or light materials. For these applications the controllable power of an X-ray generator is necessary.

DINNER DANCE

Olean—The *Olean-Bradford* Section held its annual dinner-dance on June 17th at the Castle Restaurant in Olean, N. Y. Following the dinner, retiring chairman James Matheny was presented with his past-chairman's pin and officers for the 1961-62 season were announced as follows: Chairman—James Diefendefer, Vice-chairman—Robert McAdams, Secretary—Harold Rice, Treasurer—Anthony Bartman, and Directors—Harold Collins and Frank Clemens.

The remainder of the evening was devoted to dancing.

Texas

HISTORY OF BOILERS

San Antonio—The July meeting of the *San Antonio* Section was held on July 10th at Capt. Jim's with 45 members present for the program. Raymond K. Brown, chief inspector with the Hartford Steam Boiler Inspection and Insurance Company of San Antonio was the principal speaker.

Mr. Brown's topic was divided into two parts—"Reasons for Classification and Reclassification of Welders and Welding Process" and "Inspection of Welded Pressure Fired Vessels, Covering Construction and Maintenance."

Highlights in the history of boilers were discussed. Almost 100 years ago (1865), inspection was first started on boilers to maintain uniform, safe construction and maintenance for boilers. Prior to this time, boiler explosions occurred on the average of one a day, causing much damage and operating personnel hazards. This brought about the first inspection by Hartford Insurance Co. and, in 1911, ASME came out with the Publication of Code. 1914–1926 brought about the code for locomotive boilers. In 1937 the Texas Boiler Code accepted Federal Control. Mr. Brown stated that fusion welding was a preferred method for the construction and repair of boilers by using strict procedures and controls.

Utah

ADVANCEMENTS IN WELDING

Salt Lake City—Darwin Christofferson of the Chicago Bridge & Iron Co. was guest speaker at the *Salt Lake City* Section meeting held on May 18th at the Panorama Inn. His subject was "Recent Advancements in Welding" which covered electrogas, multipass, electroslag, submerged arc and multiple electrode welding techniques.

CANYON PARTY

Salt Lake City—The June meeting of the *Salt Lake City* Section was the final meeting of the 1960–61 season and consisted of a canyon party in Little Cottonwood Canyon, east of Salt Lake City. About fifty members and their wives had a very enjoyable evening at this party.

you do the job better
with Airco quality equipment . . . this is because Airco designs, engineers and produces everything you need to do any welding or cutting job properly, no matter what it is. Airco precision components *work together better* . . . *are matched* to the job.

For specifics see the Airco ad on the back cover of this issue.

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AIR REDUCTION SALES COMPANY
A division of Air Reduction Company, Incorporated
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New Members

EFFECTIVE JULY 1, 1961

MEMBERSHIP CLASSIFICATION

A—Sustaining Member
B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Member

TOTAL NATIONAL MEMBERSHIP

Sustaining Members	204
Members	6,531
Associate Members	5,749
Students	361
Honorary Members	11
Life Members	32
Total	12,888

ANTHONY WAYNE

Delaney, Charles Edward (B)

ARIZONA

Smith, Floyd F. (B)

BOSTON

Johnson, Robert O. (B)
Rogan, Edward J. (C)

CANADA

Davenport, L. H. (B)

CHICAGO

Bilancia, Raymond A. (B)
Favero, John Paul (B)
Getts, Charles C. (B)
Haas, Robert E., Jr. (C)
Jaso, Jack (C)
Larson, I. G. (B)
Ordakowski, Walter (C)
Pitcher, James R., Jr. (C)
Steil, Gordon E. (C)
Taylor, Michael (D)
Watkins, Richard E. (C)

CLEVELAND

Dalton, Robert P. (B)
Eberle, John Donald (C)
Lipsey, Henry (A)
Taylor, John D. (C)

DAYTON

Bartko, Leonard W. (B)

FOX VALLEY

Johnson, William (B)
Liefermann, Joe (C)
Pfister, Charles J. (C)
Schmidt, Chester (C)

HOUSTON

Browning, Donald C. (C)
Koban, E. C. (B)
Nesbitt, L. P., Jr. (C)
Niederhofer, A. A. (B)
Reid, Lester S. (B)

INDIANA

Elson, Charles R. (B)

J. A. K.

Bisping, Gordon G. (C)
Braun, Charles F. (C)
Gorman, Charles V. (B)
Kerber, Ken F. (C)
Mingarelli, Henry (C)
Pickett, James A. (C)
Svetlecic, Robert J. (C)

LEHIGH VALLEY

Cole, C. Fred (C)

LOS ANGELES

Aldrich, Floyd W. (B)
Bradspies, Robert W. (B)
Taylor, Jack L. (B)

MAHONING VALLEY

Heksel, Lloyd (B)

MICHIANA

Fogle, James W. (B)

MILWAUKEE

Kotecki, Stanley F. (B)

MOHAWK VALLEY

Gregg, Henry T., Jr. (B)

NASHVILLE

Peak, William S. (C)

NEBRASKA

Hummel, Joe B. (C)
Marlatt, Jerry C. (C)
Stauffer, Howard V. (C)

NEW JERSEY

Freeman, Norman D. (C)
Morgan, Fred C. (B)
Vlin, Robert (C)
Warden, Howard C. (B)

NORTHEAST TENN.

Tolson, G. M. (C)

NORTHERN NEW YORK

Floeser, John J. (B)

NORTHWEST

Falconer, Sidney D. (B)
Mitchell, Joseph C., Jr. (C)

NORTHWESTERN PA.

Trombetta, Thomas E. (C)

ORANGE COUNTY

Castorina, Richard S. (B)

PEORIA

Mathewson, Robert I. (B)

PHILADELPHIA

Cattell, Joseph S. (C)
Demos, Anthony C. (C)
Rishel, Maurice H. (B)

PITTSBURGH

Goldberg, Lewis (B)
John, Clarence D., Jr. (B)

PORTLAND

Goddard, James P. (C)

PROVIDENCE

Barb, Raymond P. (B)

PUGET SOUND

Kolar, Francis L. (C)

ROCHESTER

Akey, Leo F. (C)

ST. LOUIS

Flanigon, Lee A. (B)

SALT LAKE CITY

Johnson, Glenn T. (B)

SAN ANTONIO

Devereaux, William A. (B)

SANTA CLARA VALLEY

Davis, David K. (B)

SOUTHWESTERN VA.

Woolwine, Frederick C. (C)

TOLEDO

Harman, Kenneth R. (B)

TULSA

Pearce, James W. (B)
Sherrill, Estill (B)

YORK-CENTRAL PA.

Sarge, Donald W. (C)

MEMBERS NOT IN SECTIONS

Rhoads, Arthur S., Jr. (B)

Reclassifications During July, 1961

CHICAGO

Molthop, Richard W. (C to B)

GREATER HUNTSVILLE

Goldstein, Sherwood (C to B)

HOUSTON

McPearson, P. K. (C to B)

LOS ANGELES

Labberton, Helios V. (D to B)

NEW JERSEY

Sullivan, Stephen L. (C to B)

NORTH TEXAS

Fouse, Jack A. (D to C)

WESTERN MASS.

McCullough, Gerard (C to B)

Important Announcement—

The Welding Journal and other AWS departments have moved to:

UNITED ENGINEERING CENTER
345 East 47th Street
New York 17, N. Y.

Telephone Number: PL 2-6800

NEWS of the industry

American Brazing Reduces Prices

American Brazing Alloys Corp., Pelham, N. Y., recently disclosed that it has revised prices to distributors on its entire line of brazing alloys. The new, lower pricing are now effective on all alloys including low fuming bronze, nickel silver, silver solder, phosphor coppers and phosphor silvers.

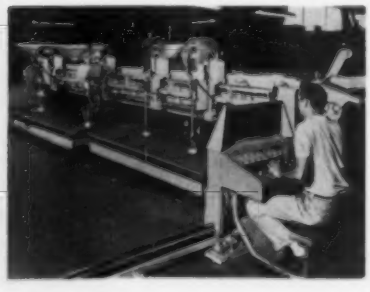
The company also announced that it is expanding its sales force by seeking additional Manufacturers Agents.

Tape Controlled Flame-Cutting Machine

The first numerical control tape flame-cutting machine—developed by Air Reduction Sales Co. in cooperation with General Electric Co.—was recently demonstrated at Airco's equipment manufacturing plant in Union, N. J.

This automatic rectilinear bridge type unit is capable of cutting straight lines and contours in up to 22 ft wide plate of any length up to 6 in. thick. The computer-oriented machine is especially suited for use in shipyards and by large and medium-sized fabricators, such as manufacturers of earth-moving equipment, electrical equipment, farm machinery and railway cars and locomotives.

A new concept in flame-cutting control, the new machine eliminates the need for templates, template tables and reliance upon an operator to control the flame-cutting process. The cutting system consists of two main components—the director, a General Electric mark century numerical contour control system, and the cutting machine proper.



The unit provides fully automatic control of flame-cutting operations by means of predetermined, numerically coded instructions. The new system has been designed to provide optimum automation of all associated operations so that the lowest cutting costs will be attained. Under this system, the part to be cut is designed and engineering drawings are prepared. A program is devised by extracting dimensional information from the drawings. This information is then transferred to paper tape by means of an automatic punch typewriter. The system is also compatable with the use of electronic computers for simplified programing.

This tape provides the input data to the cutting machine. After initial positioning by an operator, all operations are fully automatic. In addition, auxiliary functions, such as starting and stopping the machine, igniting of preheat flames, flame control, gas supply control and cut sequence, are programed on the tape. Cutting speeds, also controlled by the tape, can be programed within the limits of 2 to 35 ipm. A fast traverse speed for positioning the machine between cuts may be programed on the tape up to 150 ipm.

Equipped with four cutting torches, the unit has an accuracy of (plus or minus) $1/64$ in.

Awarded $415,000 Contract

The Babcock & Wilcox Co. recently announced that it has been awarded a $415,000 contract by the Atomic Energy Commission to design and fabricate a second head, or top closure, for the reactor in the N.S. *Savannah*, world's first nuclear merchant ship.

Under terms of the contract, the 40-ton "spare" reactor head closure will be made to accommodate control equipment of advanced design, now under development by the Borg-Warner Corp. for future use in the vessel's nuclear reactor system.

James F. Lincoln Foundation Selects Award Juries

The James F. Lincoln Arc Welding Foundation of Cleveland, Ohio, recently appointed Professor J. W. Deegan, Head, Mechanical Engineering Dept., University of Iowa; J. B. Green, Asst. Chief Engineer, Industrial Div., Jeffrey Manufacturing Co., Columbus, Ohio; C. L. Kreidler, Chief Engineer, Lehigh Structural Steel Co., Allentown, Pa.; and Van Rensselaer P. Saxe, Design Consultant, Baltimore, Md. to serve on the Jury of Awards for the $25,000 award program for Progress in Arc Welded Design.

At the same time, Professor A. J. Ferretti, Chairman, Dept. of Mechanical Engineering, Northeastern University, Boston, Mass.; F. Holtby, Associate Professor, Mechanical Engineering, University of Minnesota, Minneapolis, Minn.; and Professor Jan Tuma, Head, Civil Engineering Dept., Oklahoma State University, Stillwater, Oklahoma to serve on the Jury of Awards for the $10,000 Engineering Undergraduate Award Program.

Both juries, chairmanned by Dr. E. E. Dreese, Chairman, Dept. of Electrical Engineering, Ohio State University, will meet in August in Alanson, Mich., to judge program entries and make awards.

Entire girth weld on this Thiokol motor housing is x-rayed in one exposure.

For Thiokol's Redstone Division...

the metal parts countdown starts here

Right in the first stages of missile-motor processing, the Thiokol Chemical Corporation begins its countdown with a check—by radiography—of the soundness of each weld.

Putting power plants together for the nation's space program is intricate work.

So—Thiokol's inspection of metal parts begins with the welds because any seam weakness might well let the bird fly apart.

Also—if the motor uses a solid propellant, radiography provides Thiokol with a quick, sure way to examine the charge for unseen fissures or bubbles that could cause uneven burning and erratic runs.

There are many *ways* to use radiography, but the *reasons* remain the same. Radiography saves time and money. It assures a reliable product. You needn't be a missileman to appreciate these advantages.

If you feel your product can benefit from radiography, talk to an x-ray equipment dealer or write us for a Kodak Technical Representative to call.

Arrow points to faulty weld caught on Kodak Industrial X-ray Film.

Now . . . Ready Pack in ROLLS and SHEETS Kodak Industrial X-ray Film, Types AA and M in 200-ft. rolls (16mm, 35mm, 70mm) and sheets (8 x 10, 10 x 12, 11 x 14, 14 x 17).

- No darkroom loading—film sealed in a light-tight envelope.
- Just place Ready Pack in position and expose.
- Film protected from dust, dirt, light and moisture.
- In the darkroom—remove film from envelope and process.

Kodak
TRADE MARK

EASTMAN KODAK COMPANY
X-ray Sales Division Rochester 4, N.Y.

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"Our weldors sure do like to work with that new Murex AC machine..."

That's what everybody seems to be saying wherever the M&T Murex AC Industrial Arc Welder gets put on the job. No wonder. It's designed for easy handling and dependable service, with...

Just one inch of shunt travel for entire current range. Rigidly mounted shunt for quiet, chatter-free operation. Fast, single crank heat control. Patented dual-coil transformer in a balanced circuit for smooth, steady arc under all welding conditions. High open circuit voltages for instant starting of arc with all types of electrodes.

Write for data sheet. METAL & THERMIT CORPORATION, General Offices, Rahway, New Jersey.

M&T MUREX AC ARC WELDER

For details, circle No. 16 on Reader Information Card

COMING EVENTS

A Calendar of Welding Activity

AWS

Sept. 25–28. 1961 National Fall Meeting, Hotel Adolphus, Dallas, Tex.

AEC

Sept. 20–22. Welding Forum—Annual Meeting (classified), Granada Hotel, San Antonio, Tex.

AIPE

Sept. 12–14. Third Annual Southeastern Show. Greensboro War Memorial Coliseum, Greensboro, N. C.

ISA

Sept. 11–15. Fall Instrument—Automation Conference and Exhibit and 16th Annual Meeting, The Biltmore Hotel and Memorial Sports Arena, Los Angeles, Calif.

NWSA

Sept. 14–15. Central Zone Meeting, Palmer House, Chicago. Sept. 18–19. Eastern Zone Meeting, Hotel Roosevelt, New York, N. Y.

SES

Sept. 18–20. Tenth Annual Meeting. Hotel Sherman, Chicago, Ill.

SFSA

Sept. 25–26. Fall Meeting. The Homestead, Hot Springs, Va.

* * * *

Sept. 14–15. 9th Annual Joint Engineering Management Conference, Hotel Roosevelt, New York, N. Y.

Sept. 25–28. Industrial Building Exposition and Congress, New York Coliseum.

Sept. 27–30. Third Biennial Industrial Exposition, Roanoke, Va.

SAFETY ECONOMY

HI-AMP® GROUND CLAMPS

- Spring cannot be knocked out.
- Spring adjustment screw for easy replacement or adjusting.
- Sturdily built for excessive abuse.
- Designed especially for all-around welders needs.

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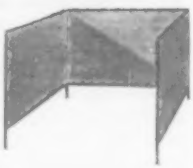
Wayne Plans Stress Analysis Institute

A two-week special Institute in Experimental Stress Analysis will be given by the Engineering Mechanics Dept. from September 11th through September 22nd. Dr. Joseph Der Hovanesian, the Institute Coordinator, announced that the Institute will be offered in two programs: Program 1—The Theory and Application of Photoelasticity—will be offered during the week of September 11th. Program 2—Strain Gage Theory and Application—will be given during the week of September 18th. Students may elect to enroll for both programs for two weeks at a tuition of $325, or for either one of the programs for one week at a tuition charge of $175.

Airco Plants Win Safety Award

Thirty Air Reduction Co. plants in the United States have been awarded certificates of safety achievement for 1960 by the Manufacturing Chemists' Association, Inc., Washington, D. C. The awards—which are presented annually to those plants which complete

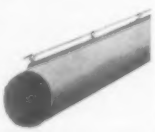
STURDY, FLAMEPROOF
WELDING CURTAINS



Any size—any shape With hem to slip over pipe or angle iron frame or with grommets for lacing curtain to frame. Build your own frame. ABC curtains of durable, wear resistant fabric, are processed to render them flameproof. Send for sample of material—give size of curtains desired if price quotation is wanted. Over 25 years experience in flameproofing of fabrics.

ABC FLEXIBLE VENTILATION TUBING

Made from flameproofed fabrics. Plain fabric and wire reinforced fabric types. Easy to hang and couple. 4" to 24" diam. For ventilating large scale welding operations. Send for literature and prices.



AMERICAN BRATTICE CLOTH CORP.
331 King's Highway Warsaw, Indiana

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a calendar year without a lost-time accident—have been made to 496 plants throughout the country.

Plants receiving the awards included those producing industrial gases, welding and cutting products; calcium carbide, acetylene and acetylenic chemicals; medical gases, therapy and anesthesia apparatus, and hospital equipment; and carbon dioxide in liquid, gaseous, and solid form.

NCG Managers Meet in Chicago

Fourteen district managers and assistants of the NCG Division of Chemetron Corp. recently attended a three-day conference in Chicago sponsored by the Midwest region. H. H. Comstock, regional manager, said the meeting was set up to study dealer relations, cost control and sales promotion, and to review new products and equipment.

Expands Semiconductor Facilities

Sylvania Electric Products Inc. Woburn, Mass., has announced that it is expanding its semiconductor division manufacturing facilities by more than 40% because of "unprecedented product demand" resulting from recent company developments in semiconductor devices and materials. Sylvania is a subsidiary of General Telephone & Electronics Corp.

Dr. William J. Pietenpol, divisional vice president and general manager, said that under the expansion program, the semiconductor division will add 81,000 sq ft of manufacturing space between mid-August and next spring.

Youngstown Licenses Babcock & Wilcox

The Youngstown Sheet and Tube Co., Youngstown, Ohio, recently announced that it has licensed the Tubular Products Div. of The Babcock & Wilcox Co. to manufacture and sell welding fittings and other products of Yoloy steel.

The license to Babcock & Wilcox is the first issued by Youngstown.

Beckman Acquires Offner

Beckman Instruments, Inc., Fullerton, Calif., and Offner Electronics, Inc., recently announced plans for pooling the interests of the two companies. The Schiller Park, Ill., manufacturer of medical and electronic instruments will become a division of Beckman. No changes are contemplated in Offner personnel.

Dr. Arnold O. Beckman and Dr. Franklin F. Offner, presidents of the two firms, said plans call for an exchange of Beckman common stock for the assets of Offner. Terms of the transaction were not disclosed.

Oxygen Converter Unit Installed

A new liquid oxygen converter that provides a continuous supply of oxygen for customers has been installed at D and R Welding Supply Co., Inc., 737 E. Division St., Decatur, Ill.

The unit enables D and R to fill gaseous oxygen cylinders to high pressure by converting the easily stored low-pressure liquid. Liquid oxygen is delivered periodically to the distributor by the National Cylinder Gas Div. of Chemetron Corp., which installed the unit.

E. C. Savant, NCG district manager, said the liquid oxygen is passed through a vaporizer and into cylinders as a gas. The converter has a capacity of 250,000 cu ft of gaseous oxygen, yet takes up a ground space of only 14 by 14 ft.

"We're using M&T's new DC machine ...it's the best we've seen, and we looked..."

And if *you* look and compare, you'll concur. The Murex 3-phase DC Welder offers the type of rectifier that works best for this service; and it features a design that simplifies operation, makes life easy for the weldor.

Silicon diodes, hermetically sealed, are non-aging and give as much as 98% efficiency. Electrical circuit is designed for instant recovery voltage so that arcs are easily struck, stabilized, and maintained. Simple knob and selector make control of heat and polarity very easy.

Write for data sheet. METAL & THERMIT CORPORATION, General Offices, Rahway, New Jersey.

M-T MUREX DC WELDER

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"I hear the Muretran* welder can handle any type of welding... man, is it engineered!"

Word gets around fast. M&T's "Muretran" Welder is the most versatile ever developed for its field of application. Look at this array of features:

Suitable for manual, automatic, inert gas (MIG, TIG), and spot welding—with quick changeover from one to the other. Plug-in timers for gas pre-flow, post-flow, high frequency drop-out, spot arc. Patented, dual windings in saturable shunt transformer. Sealed non-aging silicon rectifiers for highest efficiency. Want to hear more about M&T's welders?

Write for data on AC-DC and AC units. METAL & THERMIT CORPORATION, General Offices, Rahway, New Jersey.

*Trademark

MURETRAN All-Purpose WELDER

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Hobart Award

E. A. Hobart, (right), Hobart Brothers Co., presents fellowship to Professor Roy B. McCauley, Ohio State University

Hobart Awards Ohio State Fellowship

E. A. Hobart, president of Hobart Brothers Co., recently announced the gift of a Hobart Brothers two year graduate fellowship to Ohio State University. The gift was presented to Roy B. McCauley, chairman of the Department of Welding Engineering at Ohio State.

The fellowship will amount to $1800 per year for a two year period (a nine month program each year). It will enable a qualified young man to obtain his Masters Degree in Welding Engineering from Ohio State University. With this graduate program, the recipient will be responsible for fundamental research activity in the welding field, and will also do some teaching along with his educational pursuits.

Hobart Brothers Co. will offer the student the opportunity of working in their plant during the summer period between the two year programs—which will provide him with work experience and additional funds. They will also provide a program of assistance to help the student obtain the materials and supplies necessary to conduct the research program he works on.

New Ampco Distributor

Eastern Welding Equipment Co., Inc., Westbury, N. Y., will serve as the Long Island and New York City distributor of Ampco weldrod products, according to Ampco Metal, Inc.

Effective at once, the newly-appointed distributor will handle Ampco's complete line of bronze welding electrodes, bare filler rods and wire in spooled and coiled forms.

Aronson Names Representatives

Aronson Machine Co. Inc. has named two new representatives to its Eastern sales district: The Harvey Co., Greensburg, Pa., with three branch offices in Western Pennsylvania and Welder Sales and Service Inc. of Youngstown, Ohio. Both are authorized to distribute and service Aronson products.

WELDING ENGINEER

Marion Power Shovel Co. offers a challenging responsibility for a Welding Engineer experienced in all phases of heavy weldment fabrication.

Position requires thorough knowledge of manual, semi-automatic and full automatic welding processes; ferrous welding metallurgy; distortion control of large structures; and structural design analysis.

Applicants should be graduate Welding, Mechanical or Metallurgical engineers with minimum of 3 years experience.

Please send resume to:

Industrial Relations Dept.
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American Iron Makes 1000 Friction Welds

Recently for the first time in the free world, friction welding was used to fill an industrial order. The unprecedented production run took place at the Oklahoma City plant of American Iron & Machine Works Co., Inc., a subsidiary of American Machine & Foundry Co. of New York. The welds were made on a

prototype machine developed by AMF's research & development division.

Another new development in the historic welding job, was an American Iron-designed small diameter tool joint which was welded to small diameter tubing.

The tool joint welding contract was let to American Iron by Oil Field Rentals, Inc., Fort Worth, Tex., and involved 15,000 linear ft. of $1\frac{1}{4}$ in. tubing. Approximately 1000 welds were made on the prototype machine in welding male and female tool joints (1.750 in. diam).

Tru-Fit Screw Forms Welding Division

Tru-Fit Screw Products Corp., Cleveland, Ohio, with 35 years of experience in special fasteners, recently announced formation of the Tru-Weld Div., which will manufacture quality engineered shear connector studs designed for economical composite construction.

NCG to Build in Texas

A dual-purpose on-site air separation plant will be built by the National Cylinder Gas Div., Chemetron Corp., Chicago, at Texas Instruments Inc., Dallas, according to a recent announcement. The plant, which will cost more than a million dollars, will have capacity of 120 tons per day of oxygen, nitrogen and argon.

J. L. Adank, NCG division president, said the facility will be capable of producing both liquid and gaseous products.

"This flexibility will provide 'built-in' protection for Texas Instruments by making possible a large reserve supply which can be piped into the company as needed. NCG will market the additional output of the plant to other customers throughout the Southwest," Adank said.

Lincoln Holds International Arc Welding Course

The Lincoln Electric Co.'s application engineering department under the direction of R. A. Wilson, vice president, recently completed an international arc welding education program. A five week course covering application of the various welding processes was held at Lincoln's Cleveland plant and was attended by industrial application engineers representing the Armco International Corp. in England, Argentina, Peru, Brazil and Mexico.

Attendance at a supervisors welding seminar completed the program. This seminar, one of a series conducted by Lincoln to expand the use of arc welding, provided an opportunity for these men to meet and exchange ideas with more than 29 welding supervisors and management personnel representing 19 companies from all parts of the United States.

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PORTABLE AC WELDERS

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2,944,140—HIGH-INTENSITY ELECTRICAL PLASMA-JET TORCH INCORPORATING MAGNETIC NOZZLE MEANS—Gabriel M. Giannini, Newport Beach, and Vernon H. Blackman, Laguna Beach, Calif., assignors to Plasmadyne Corp., Santa Ana, Calif., a corporation of California.

The apparatus disclosed by this patent includes electric means to generate a stream of plasma and means to generate a strong magnetic field surrounding and adjacent to at least a portion of such stream. The lines of magnetic force of the field are shaped generally as a venturi having a throat and having portions diverging in opposite directions from the throat axially of the stream. The magnetic venturi is coaxial to the stream so that the stream passes there through for stabilization and concentration action.

2,944,141—APPARATUS FOR ELECTRIC ARC WELDING—Rodger T. Lovrenich, 21456 Karl, Detroit 19, Mich.

This patent is on apparatus for indexing a crack in an electrically grounded metal piece. The apparatus includes an indexing electrode adapted to be moved across the surface of the metal piece to introduce an electric current into the piece, and a pair of auxiliary electrodes are provided spaced from each other and from the indexing electrode. The apparatus is completed by electrical means used to detect differences in electrical potential between the auxiliary electrodes.

Abstracts of Current PATENTS

prepared by Vern L. Oldham

Printed copies of patents
may be obtained for 25¢ from the
Commissioner of Patents, Washington, D. C.

2,944,142—ELECTRIC ARC WELDING ELECTRODES AND METHODS OF MANUFACTURING THE SAME—Per Yngve Sjoman, Goteborg, Sweden, assignor to Elektriska Svetsnengsaktiebolaget, Goteborg, Sweden, a corporation of Sweden.

The present patent is on an electrode for electric arc welding and the electrode includes a sheath of low-carbon iron and a metal powder core. The core consists of one single powdered alloy containing at least two nonferrous metals and with the weight of the metal powder core being not less than 10% and not more than 50% of the combined weight of the sheath and the core.

2,945,116—METHOD FOR CONTROLLING THE TRAVEL OF WELDING MACHINE USED FOR ELECTRICAL ARC WELDING INTO MOLTEN SLAG—Martin Mosny, 14 Zahradnicka, and Viliam Pavelka, 9 Jeruzalemska, both of Bratislava, Czechoslovakia.

In this patent, apparatus for electric welding action in a bath of molten flux along edges of workpieces which extend at a substantial angle to the horizontal is disclosed. In the apparatus, a welding machine is positioned to be movable upwardly along the edges of the work pieces as the welding proceeds and special controls are provided for moving the welding machine upwardly as the welding action progresses and dependent upon weld conditions for welding machine movement.

2,945,117—METHOD AND APPARATUS FOR REMOVING WELDING FLASH—Jean F. Harris and Harry W. Horlacher, Warren, Ohio, assignors to The Taylor-Winfield Corp., Warren, Ohio, a corporation of Ohio.

The present patent relates to flash-welding apparatus including a pair of opposed welding die assemblies each of which is split to provide an upper and lower die member. The apparatus also includes means for separating such upper and lower die members with each die assembly having an end face of predetermined shape such that the welding flash about the welded work pieces is broken away from the workpieces by separation of the die members.

2,945,118—STUD WELDING APPARATUS—Frank K. Kelemen and Ralph K. Ritter, Haddonfield, N. J., assignors to KSM Products, Inc., Merchantville, N. J., a corporation of New Jersey.

In this new stud-welding apparatus, a spindle is mounted for movement forwardly and rearwardly in a carrier housing. Among other parts of the apparatus, a control switch is mounted in the housing in the path of rearward movement of the spindle to contact it and complete an electric circuit through the spindle on such rearward movement.

2,945,119—STABILIZED MAGNETIC NOZZLE FOR PLASMA JETS—Vernon H. Blackman Laguna Beach, Calif., assignor to Plasmadyne Corp., Santa Ana, Calif., a corporation of California.

Blackman's patent is on a stabilized magnetic nozzle means for a substantially arc-free stream of ionized gas. The nozzle means includes means for creating a magnetic field through which the stream passes, and means to maintain an electric arc in the stream adjacent such magnetic field.

2,945,161—CIRCUIT ARRANGEMENT FOR THE CONTROL OF WELDING VOLTAGE—Henri Joseph Antonius Marie Jacobs, Leonardus Fransiscus van de Weijdeven and Lambertus Wilhelmus Roosendaal, all of Eindhoven, Netherlands, assignors to North American Phillips Co., Inc., New York, N. Y., a corporation of Delaware.

The present patent covers a novel but specialized circuit arrangement for the control of welding voltage, but with the circuit also being usable for other purposes.

2,945,296—METHOD OF AFFIXING FINS TO TUBING—Dougan L. Jones, Lees Summit, and Cornelis Langewis, Hickman Mills, Mo., assignors to The Marley Co., Kansas City, Mo., a corporation of Delaware.

In this patent, a method of brazing an aluminum fin on a tube having an outer surface of copper is disclosed. A substantially fluid coating is placed on the outer surface of the tube and includes specified percentages of zinc oxide, zinc chloride, ammonium chloride and sodium fluoride as well as water. The fin is then brazed to the tube under specified brazing conditions using the composition indicated.

2,945,937—SUBMERGED-ARC WELDING—Antony Brian Tinsley, Stourport-on-Severn, and Kenneth Guest, Brierley Hill, England, assignors to Imperial Chemical Industries Ltd., Millbank, London, England, a corporation of Great Britain.

The present patent on a submerged-arc welding apparatus includes a trough for containing flux, an adjustable base portion in the trough, and including a slidable member resting on an inclined surface. Other means are provided for imparting relative sliding movement between the slidable member and its support surface. Such member can be moved toward and away from a trough opening for control of welding action in the trough.

2,945,939—ROTARY WELDING ELECTRODES—John D. Russell, 6830 Alta Loma Terrace, Hollywood, Calif.

Russell's patent relates to a hand-guided welding electrode unit including a hollow handle with a roller type electrode rotatably mounted on bearing means within the handle. An electric motor is associated with the welding electrode unit for driving the gear means connected to the roller type electrode assembly for rotation thereof.

2,945,940—RESISTANCE WELDING PROCESS—Hans A. Schlatter, Zollikon, Zurich, Switzerland, assignor to H. A. Schlatter, Aktiengesellschaft, Zollikon, Zurich, Switzerland.

Schlatter's patent is on a flash-butt resistance welding process wherein flashing is obtained by applying current to two pieces to be welded together and feeding them toward each other. The portions of the members substantially adjacent the area of contact being in semiliquid condition, and the portion adjacent thereto being in forgeable condition. The boundary plane between these portions of these members moves during the flashing away from the area of contact at a certain speed. The members are moved toward each other at a certain speed to obtain some flashing action and then after a period of such flashing, the members are moved toward each other at a second and higher feeding speed to move the boundary layers into substantial contact with each other and weld these portions, which are in forgeable condition, directly to each other.

2,945,941—RESETTABLE WELDER—David Kalish, Alliance, Ohio, assignor to The Alliance Manufacturing Co., Division of Consolidated Electronics Industries Corp., Wilmington, Del.

Kalish's patent is on apparatus including an electrode for cooperating with a work piece at a welding station, and resettable means for resetting the distance of the electrode with relation to the work piece at the weld station. Control means are provided for the welding current circuit, and another member is present to cause actuation of the control means a plurality of times between actuation of the resetting means.

2,945,942—METHOD OF WELDING—Thomas J. Flynn, Verona, and Walter G. Sylvester, West Caldwell, N. J., assignors to Specialties Development Corp., Belleville, N. J., a corporation of New Jersey.

The present method of electric arc welding together is for securing opposed edges of adjacent wall members together. The wall members are composed of ferrous metal and each have at its edge a lower portion of reduced thickness providing an upwardly facing recess and terminating in a relatively short depending portion. In the welding process, the flat depending portions are abutted, and an electric arc is drawn between the upper surfaces of the members at the reduced thickness ends for a sufficient length of time to melt and puddle the depending portions, and this electrode is moved along in a direction to follow a groove formed between the members. As the members cool, the puddle is drawn upwardly to provide a substantially smooth, continuous surface at the undersides of the members at the weld. Next ferrous metal of the same composition of the members is placed in the groove, melted and the groove is filled with the molten ferrous metal to butt weld the members together.

2,945,943—WELDING SHIELDING AND CONTROL DEVICE—Amel R. Meyer, Griffith. Ind., assignor by mesne assignments, to Union Tank Car Co., Chicago, Ill., a corporation of New Jersey.

Meyer's patent on a special welding shield and control device includes means therein by which a viewing lens can be positioned adjacent a welding action so that an image can be provided on a screen adjacent the weld point so that an image of the welding arc can be viewed through the apparatus.

Current Welding LITERATURE

For copies of articles, write directly to publications in which they appear. A list of addresses is available on request

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PERSONNEL

Reuter Named by Eutectic

John W. Reuter was recently named division manager in eleven western states as well as Alaska and Hawaii for Eutectic Welding Alloys Corp., Flushing, N. Y.

Mr. Reuter was previously head of western product and market research. He will supervise Eutectic's regional, district and service center managers, as well as technical representatives in that area. His headquarters will be at the new Eutectic warehouse in Oakland, Calif.

New Staff Post Filled by Leupold

Glenn W. Leupold was recently advanced to fill a new post on the president's staff at Cleaver-Brooks Co., a manufacturer of packaged boilers. He will serve as managing director of foreign manufacturing and, on the local scene, will monitor and coordinate the transition of engineering developments into regular manufacturing channels.

Leupold is a member of Beta Theta Pi fraternity and served as past chairman and director of the AMERICAN WELDING SOCIETY

Haynes Stellite Names Kroft

Frederick C. Kroft AWS has been appointed staff assistant to the president of the Haynes Stellite Co., Div. of Union Carbide Corporation, according to an announcement by R. M. Briney, president of the company.

Mr. Kroft, formerly works manager, received a B.S. degree in metallurgy from Purdue University in 1942. He joined Haynes Stellite in 1936 and worked in the grinding department and chemical laboratory. He became a junior research engineer in 1942. In 1949 he was assistant technical director, and was appointed superintendent of inspection, process and quality control department the following year. In 1955, he was named works manager.

Southwest Research Appoints Wylie

The Southwest Research Institute of San Antonio, Tex., recently announced the appointment of Robert D. Wylie AWS as director of the Dept. of Materials Engineering.

Before joining Southwest Research, Mr. Wylie was with the Babcock and Wilcox Co. where he was active in the development of components for various Navy and commercial nuclear systems, including the Nautilus, Seawolf and the N.S. Savannah. He also developed several new materials for use in high temperature steam plants. Wylie has served as an advisor to the Naval Bureau of Ships on welding of high strength steels for submarine hull construction.

Mr. Wylie is a member of the American Society of Metals. In 1960, he was program coordinator for the National Metal Congress in Philadelphia. He is a member of several subcommittees of the Boiler and Pressure Vessel Code Committee of the American Society of Mechanical Engineers. He is a member of two standing Committees of the American Welding Society, and was a member of the Welding Research Council's Pressure Research Committee and the High Alloys Committee.

Allis-Chalmers Appointments

The Allis-Chalmers Manufacturing Co., Milwaukee, Wis., recently announced the following appointments: H. W. Cory—assistant general manager, Norwood Works; D. H. Lory—assistant works manager, Norwood Works; A. Wassell—manager of utility sales, Charleston district; W. W. Chalmers—manager, Chattanooga district; T. L. Dineen—manager, Cleveland district; J. H. Jones—manager, El Paso district; M. S. Jones—manager of western accounts, Cement Industry Dept.

ASTM Award to Eagan

An award of merit was presented to Thomas E. Eagan, AWS, chief research metallurgist, the Copper Bessemer Corp., Grove City, Pa., at the 64th Annual Meeting of the American Society for Testing Materials in Atlantic City, N. J.

The award was in recognition of outstanding contributions by Mr. Eagan to the field of ferrous metals.

Wenk Joins White House Staff

Edward Wenk, Jr., was recently appointed Executive Secretary to Federal Council for Science and Technology. In this capacity he will serve as technical assistant to Dr. J. B. Wiesner, Special Assistant to the President for Science and Technology. Previously, Dr. Wenk was Senior Specialist in Science and

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Dr. Wenk is a member of the American Society of Civil Engineers and has served for the past three years as Secretary of the Engineering Mechanics Division; he is past national president of the Society of Experimental Stress Analysis and currently chairman of its Editorial Board; is a member of the American Society of Mechanical Engineers and of the Special Committee to Review Code Stress Basis; a member of the Pressure Vessel Research Committee and past chairman of its Design Division and chairman of a Task Group on Deep Diving Submarines of the National Academy of Sciences' Committee on Undersea Warfare. He is also a member of the American Rocket Society, and the American Association for the Advancement of Science. He holds a number of patents in the field of experimental test apparatus and on submarine hulls.

Swords Named Representative

Swords Supply Service, with headquarters in Atlanta, Ga., will represent American Industrial Safety Equipment Co., Cleveland, Ohio, in the Southeastern territory, it was recently announced. P. A. "Nick" Swords, Jr., who heads the representative firm has a long and varied background in the safety field. After eight years in the Naval Service, "Nick," as he is known, was associated with the Linde Co. in Atlanta for ten years, then joined Southern Oxygen Co. in Roanoke, Va. and most recently was in the employ of Ford Supply Co., distributors of welding and safety equipment in Atlanta.

In a further development, "Nick" Swords was also appointed a factory sales representative for the Thermacote Co., Pasadena, Calif.

Honorary Degree to Goodrich

At the fortieth commencement of Western New England College in Springfield, Mass., Harley B. Goodrich, secretary of the Western Massachusetts Section of the AMERICAN WELDING SOCIETY was awarded an honorary degree of Doctor of Laws. He was chairman of the Section in 1959 and has served as secretary of the Section for two years and at the last annual meeting was elected secretary for another term.

Dr. Goodrich is Maintenance Engineer for the Strathmore Paper Co. in Massachusetts. During the War years he also served as Safety Engineer and is a member of the American Society of Safety Engineers.

Nottingham Appoints Manager

Appointment of Vincent P. Greeley as manager of the New England region has been announced by Walter G. Roe, manager-sales of J. B. Nottingham & Co., Inc., 441 Lexington Ave., New York 17, N. Y.

Mr. Greeley is responsible for sales and service of Nottingham portable equipment for multi-arc welding, stress relieving, and power distribution in Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont. His office is at 697 E. Sixth St., South Boston, Mass.

Since 1948, Mr. Greeley had been a sales engineer and service manager with construction equipment firms in New England. Previously, he had been a U. S. Air Force base engineer.

Remley Becomes Advertising Assistant

The appointment of Ronald F. Remley as assistant advertising manager for the RegO Div. has been announced by R. E. Owen, advertising manager, the Bastian-Blessing Co., Chicago, Ill. Remley, formerly advertising copywriter, will be responsible for advertising and sales promotion activities for the division, which manufactures valves, regulators and fittings for the LP-Gas and related industries.

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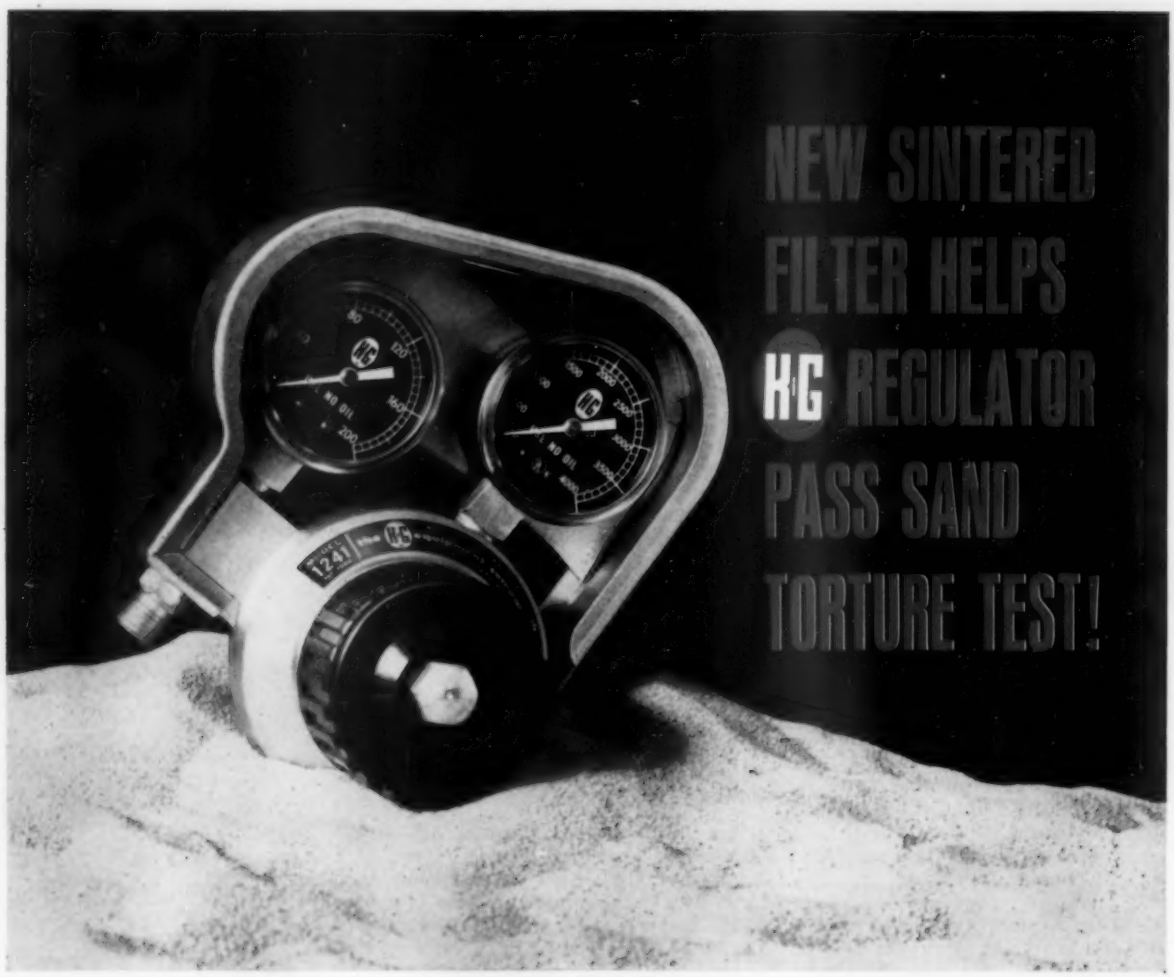

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Gaudin Re-elected Chairman

The Engineering Foundation, research department of United Engineering Trustees, Inc., recently announced the re-election of Professor Antoine M. Gaudin, Massachusetts Institute of Technology, as chairman.

Three new Directors were also elected: Dr. Hugh L. Dryden, Deputy Administrator, National Aeronautics and Space Administration; Member-at-Large, Latimer F. Hickernell, of Hastings, N. Y., Vice President-Engineering, Anaconda Wire and Cable Co.; Member-at-Large, Roy A. Kinckiner, of Wilmington, Del., Deputy Director, Engineering Research Laboratory, Engineering Department, E. I. duPont de Nemours & Co., representing the American Institute of Chemical Engineers.

United Engineering Trustees, Inc. consists of several engineering societies; it is owner and operator of the new United Engineering Center which will house 18 professional engineering organizations and will be the largest assembly of engineering organization headquarters in the world.

Graver Tank Names Turbyville

Frank H. Turbyville, Jr., has been named plant manager for the new Lockeford, Calif., plant of Graver Tank & Mfg. Co., according to an announcement by Clark Root, president.

A native of Tennessee, Turbyville holds his BSME degree from Alabama Polytechnic Institute at Auburn, Alabama. He is being transferred from Graver's East Chicago, Ind., plant and has already assumed his new duties at Lockeford.

Graver's plant was built to furnish initially large-diameter pipe sections for the great Mokelumne aqueduct supplying water to Oakland and the East Bay Municipal District. The plant includes the most modern and efficient fabricating equipment.

Weltronic Appoints Small

Following a recent meeting of the Board of Directors, C. J. Collom, president, announced the appointment of Eugene Small to vice-president of Weltronic Co., Detroit. Mr. Small will continue his duties as General Manager of the Weltronic Co. Canadian Division, Windsor, Ontario. Weltronic Co. is the world's largest manufacturer of Electronic Resistance Welding and Special Controls, with Sales and Service throughout United States, Canada and the United Kingdom.

Shelton Named by Haynes Stellite

G. H. Shelton has been appointed works manager, Haynes Stellite Co., Div. of Union Carbide Corp., according to an announcement by W. B. McFerrin, vice president of manufacturing. Mr. Shelton, formerly assistant works manager, succeeds F. C. Kroft who has just been appointed staff assistant to the president of the company.

Mr. Shelton received a B.S. degree from Oklahoma University in 1936. He joined Haynes Stellite as assistant office manager in 1948, after spending the four previous years with Union Carbide at Oak Ridge National Laboratories as a materials supervisor. Mr. Shelton was office manager and later superintendent of refined oils for Southport Petroleum Co., Texas City, Tex., from 1936 to 1944.

Curry Appointed at Hughes

Robert W. Curry was recently named marketing manager of Hughes Aircraft Company's vacuum tube products division, Oceanside, Calif.

Curry was formerly manager of systems contracting, major defense systems division, Radio Corporation of America, Moorestown, N. J.

Curry will be responsible for overall market development of division products which include direct display storage tubes, electronic welding equipment and high vacuum measuring devices.

Ingalls Elects Kopp as President

W. H. Hulsey, board chairman of the Ingalls Iron Works Co., Birmingham, Ala., today announced election of new Board Members Sam M. Boykin, Jr., and J. B. Koop. Also announced was the election of three Company Officers to serve in higher positions. J. B. Kopp was elected as president, M. H. Osburn was elected as treasurer, and J. P. Bradford was elected secretary.

Mr. Hulsey further announced management changes in the Ingalls Steel Construction Co., a wholly owned subsidiary engaged in the erection of steel fabricated. New Officers elected were J. B. Kopp, president; M. H. Osburn, treasurer; D. H. Bradley, vice president; and J. P. Bradford, secretary.

Matthews Named Group Leader

Norman A. Matthews has been appointed Group Leader, Ferrous Metallurgy, at the research laboratory of the International Nickel Co., Inc., at Bayonne, N. J., according to

. . . give steelmaker's billet mill guides 900% longer service life

"One month is good service life for new, unprotected mill guides subjected to the severe abrasion, shock, and high temperatures of rolling mill operations," said Mr. Ken Geisselhart, Blooming and Billet Mills Supt. at Pittsburgh Steel Company's Monessen, Pa., Works. "Guides surfaced with McKay Hardalloy 61 weld metal consistently give us nine to twelve months of trouble free service."

"The weld metal deposited by McKay Hardalloy 61 Electrodes is uniformly hard over the entire wear area," said Mr. Geisselhart, "and provides excellent wear resistance as is evident by 900% longer life span of surfaced guides over new unprotected guides. Production downtime and replacement costs have been reduced substantially by use of surfaced mill guides."

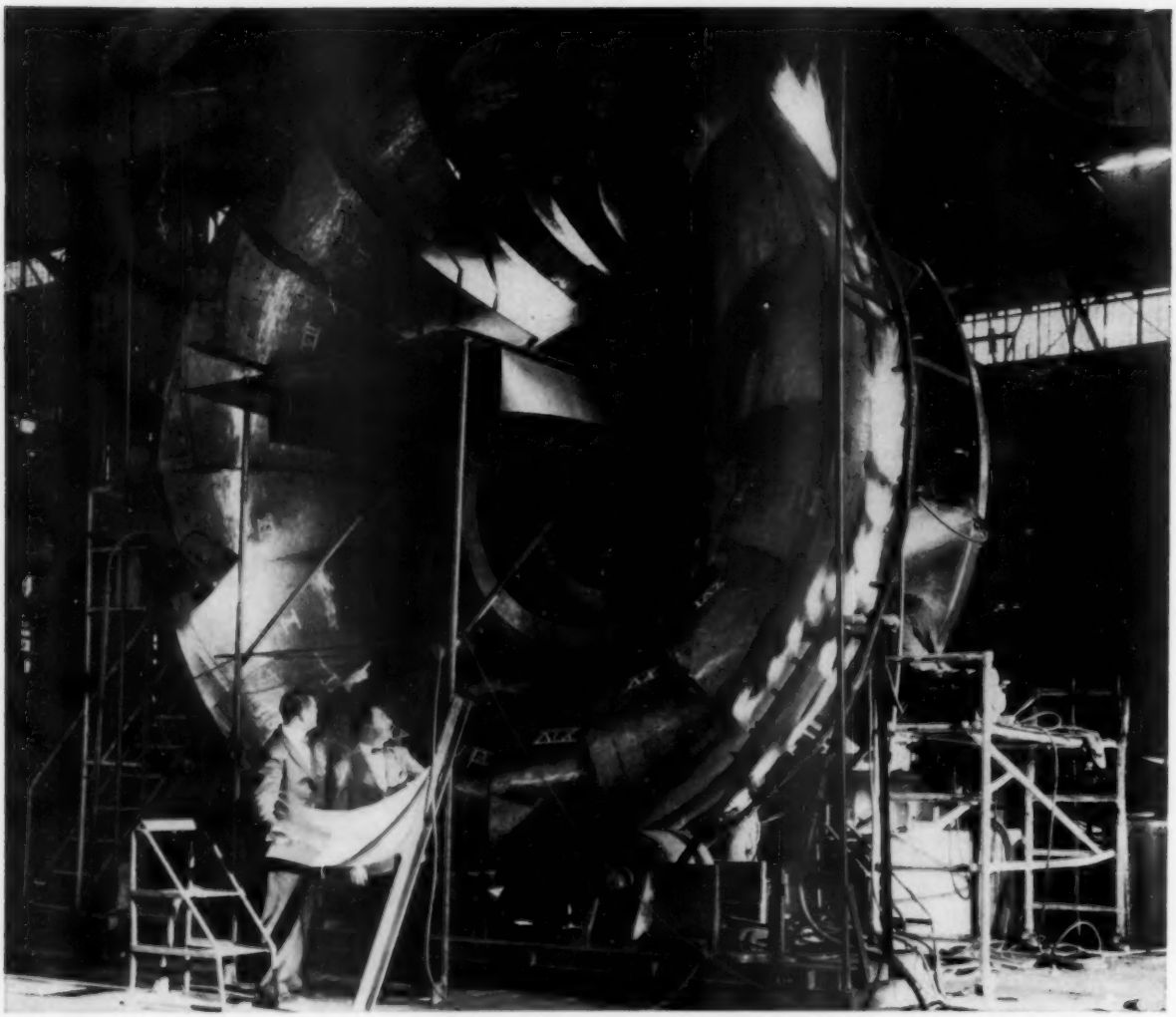
WRITE FOR McKay's 20-page Hard Surfacing catalog which contains detailed alloy recommendations and welding procedures for the repair and reclamation of many different types of equipment.

M-2

THE McKAY COMPANY

401-A McKay Bldg. • PITTSBURGH 22, PA.

For details, circle No. 27 on Reader Information Card



For X-ray quality welds in low alloy high tensile steels . . .

specify ATOM • ARC® electrodes

Since the introduction of Atom • Arc all position iron powder low hydrogen electrodes in 1954, they have become famous for one outstanding quality . . . X-ray sound welds. Other Atom • Arc qualities, of course, have been profitable and advantageous to the user. However, no one quality has saved as much time and money for the discerning fabricator or steel erection contractor as the X-ray soundness of the weld metal. Chipping and rewelding defective areas has been reduced to a minor factor where Atom • Arc electrodes are used.

For X-ray quality welds, higher deposition rates and superior arc characteristics, we suggest that you specify Atom • Arc iron powder low hydrogen electrodes. They are available in strength levels and chemistry for the welding of nearly every type of low alloy high tensile steel. To find out how these outstanding electrodes fit into your welding needs, send for "Handbook for Welding Low Alloy High Tensile Steels." Write to Alloy Rods Company, P. O. Box 1828, York, Pa.

ALLOY RODS COMPANY

YORK, PENNSYLVANIA

SALES OFFICES AND WAREHOUSES • BOSTON • NEWARK • PHILADELPHIA • PITTSBURGH • BIRMINGHAM
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low hydrogen electrodes high moisture

END THIS COSTLY AFFAIR BY KEEPING YOUR RODS AT HOME *in*

PHOENIX DryRod®

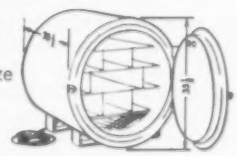
ELECTRODE OVENS

Pioneer and Leader in the Field

Dry Rod is the Trademark of Good welding everywhere

TYPE 300
350 lb size

TYPE 900
1100 lb size



TYPE 10
Portable
10 lb size

Also available:
Type 1000 (800° or 1000°)
High temperature Re-baking ovens

Welding electrodes are a perishable product. Reworks are extremely costly. Insure good welds with Dry Rod Ovens. Write for folder "Dry Rod as Standard Welding Equipment".

PHOENIX PRODUCTS COMPANY
4753 N. 27th Street • Milwaukee 9, Wis.

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an announcement by Dr. W. A. Wesley, manager of the laboraotry.

Prior to his association with International Nickel, Mr. Matthews was with the General Electric Co. and the American Brake Shoe Co. research center. He was previously on the staff of the United States Army's Watertown Arsenal Laboratory, Watertown, Mass.

Wyatt Appointed Armour Vice President

Dr. James L. Wyatt, 37, has been named vice president for program development at the Armour Research Foundation of Illinois Institute of Technology.

For four years prior to joining ARF, Wyatt was an associate in the New York offices of Booz-Allen and Hamilton, management consultants. During this period he specialized in research and development management, systems and procedures and new product planning programs.

In his new position Wyatt will plan and coordinate all promotional activities for government and industrial research and will assist in the planning and development of new fields of research.

EMPLOYMENT SERVICE BULLETIN

Services Available

A-755. Salesman. Ten years experience in all phases of gas and electric welding. Residence Los Angeles area desired. Familiar western markets. B.S. degree. Will travel. Age 35.

A-756. Specialist welder. Three U.S.A.F. certifications. Desires position in manufacturing methods or the quality control of weldments and/or allied processes; welding analyst, technician or aide to the welding engineering staff (metallurgy).

A-757. Mechanical Engineer. Seven years diversified supervisory experience in welding development training and sales in aircraft and industrial fields. Experience includes manual and automatic TIG, MIG and arc welding as well as electrode development and testing. Also, oxyacetylene processes and piping and supply of industrial gases. Considerable experience in design, promotion and installation of automatic electric welding processes and fixtures. Résumé available.

. . . efficiently weld critical pumping weldments

"We use McKay D.C. Titania Stainless Steel Electrodes because we get fewer flaws in the weld deposit," said Mr. Mike Underwood, Shop Supt., of Vulcan Manufacturing Co.

In the fabrication of these primary and secondary pumping units for a critical application, Vulcan uses McKay Type 308 and 310 D.C. Titania Electrodes exclusively. All welds have to pass dye penetrant inspection; some welds also are X-rayed, and others are subjected to a helium leak test so critical that it shows up flaws in the parent metal.

"McKay Electrodes have reduced our production costs substantially, said Mr. Underwood. Sound welds save time-consuming rewelding . . . smooth flat beads require less grinding to blend weldments with parent metal."

Got a welding problem? Look into McKay's complete line of Welding Electrodes and Automatic Welding Wires.

WRITE FOR new catalog on the "Welding of Stainless Steels." Provides data on chemical analysis, mechanical properties, corrosion resistance and types of electrodes available for welding stainless steels.

M-3

THE McKAY COMPANY

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For details, circle No. 30 on Reader Information Card

New Literature

High-Temperature Strength Data for Metals

A packaged system of code-punched cards to provide industry with current high-temperature strength data of metals and alloys is now available from the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa. The high-temperature strength data recorded on the punched cards are collected and compiled by the ASTM–ASME Joint Committee on Effect of Temperature on the Properties of Metals.

The cards carry a maximum of high-temperature data including: chemical composition, heat treatment, microstructure, hardness, short-time tensile properties, original creep and rupture data, and creep and rupture strength. They are punched-coded for selective sorting by material, form, type of test, alloy, producer of the material and source of data.

For initial distribution the cards are supplied in Groups of about 25 each:

Group I—Light alloys (not yet available).

Group II—Iron and steel including the AISI stainless steels. $7.50 for 25 cards.

Group III—Superalloys, refractory alloys and miscellaneous alloys. $7.50 for 25 cards.

Cuts across Groups I, II, and III—$7.50 for 22 cards.

A complete code book with sorting instructions accompanies each set of cards.

Manganese Rods, Weldments

A colorful, 16-page, "how to" booklet has been published by Dept. A, American Manganese Steel Div., American Brake Shoe Co., 389 E. 14th St., Chicago Heights, Ill. It offers instructions and welding tips useful in the repair and rebuilding of worn parts. Typical applications are dipper teeth, tractor grouser bars and crusher parts.

For your free copy, circle No. 55 on Reader Information Card.

Preparing Aluminum For Resistance Welding

A completely new, 8-page, illustrated booklet entitled "The Chemical Preparation of Aluminum for Resistance Welding" has just been released by Oakite Products, Inc., 157 Rector Street, New York 6, N. Y., manufacturers of specialized chemical compounds for industrial cleaning and related operations. The theme of the booklet is that "the removal of high resistance oxide films from aluminum is most simply and efficiently accomplished chemically."

Among the major topics discussed in the booklet are cleaning in preparation for deoxidizing, cold and hot deoxidizing and etch-cleaning to obtain a mat finish. The booklet probes into the variables involved in resistance welding and points out that "more important than resistance limits is uniformity of resistance."

In addition, the booklet contains complete, detailed outlines for four specific weld preparation procedures, numerous suggestions for achieving the best welding results, a procedure for deoxidizing sheet stock, capsule descriptions of seven products which are recommended in the booklet and an explanation of the importance of rinsing and drying.

For your free copy, circle No. 56 on Reader Information Card.

Metal Quality Control

A new 4-page folder titled "Automatic X-ray Spectrograph Speeds Analyzing of Metals," reprint of an article describing Westinghouse foundry operations, is now available from Philips Electronic Instruments, 750 South Fulton Ave., Mount Vernon, N. Y.

The article discusses the analysis of electric arc furnace charges in minutes as compared to former methods which provided answers days after casting were completed.

The folder covers X-ray quality control of raw materials and finished products involving copper, manganese-bronzes, tin-bronzes, aluminum-bronzes, tin-base and lead-base materials.

Special sections in the folder tell how samples are prepared, give specific figures on accuracy, and provide special data on high-conductivity copper together with gates and risers.

Photos, charts and diagrams are used for illustrations.

For your free copy, circle No. 57 on Reader Information Card.

Speed Measurement Systems

Bulletin GEZ-3251, 12 pages, describing G-E's complete line of a-c and d-c tachometer generators and indicators was recently issued by General Electric Co., Schenectady 5, N. Y. Bulletin relates information on instruments' applications, calibration, accuracy, and method of selection. Specifications, schematics and photos of the measurement systems described are also included.

For your free copy, circle No. 58 on Reader Information Card.

Vibratory, Power Rectification Equipment

A new condensed catalog of vibratory materials handling equipment, vibrating parts handling equipment, mechanical shaft seals, paper joggers, portable power tools and power rectification equipment has been published by Syntron Co., 258 Lexington Ave., Homer City, Pa.

The new catalog, No. 616, contains over 200 illustrations and presents descriptions, data and specifications on all Syntron products. It also includes listing of Syntron representatives.

For your free copy, circle No. 59 on Reader Information Card.

Carbide Grinding, Cutting Wheel

Kasco, 3461 E. 26th St., Los Angeles, Calif., manufacturers of a complete line of aluminum oxide and silicon carbide grinding and cutting wheels, has announced the release of its first comprehensive catalog.

The firm has recently developed many advanced safety and time-saving features in abrasive wheels produced especially for both metals and masonry. Included in this catalogue is descriptive information on safety hub disks, made with an exclusive metal hub center for maximum safety and reliability.

For your free copy, circle No. 60 on Reader Information Card.

No other tool saves so much time . . .

Arcair process cuts special cutting time 50%

The Gaston County Dyeing Machine Co., Stanley, N. C., needed a method for speeding special cuts made on stainless steel pressure dyeing and drying vessels and plant machinery.

Metal saws took too much setup time and cutting with regular electrodes required extensive grinding to produce good quality finishing.

Arcair torches have solved the problem. Special cutting time has been cut by fifty percent.

No matter what metal you work with, Arcair can save you time and money. Call your local Arcair dealer or write for further information. Arcair Company, Dept. 31, Box 406, Lancaster, Ohio.

A10

For details, circle No. 31 on Reader Information Card

Case History Reports

A new 8-page folder, (Bulletin A-4) published by The McKay Co., 1005 Liberty Ave., Pittsburgh 22, Pa., contains case history reports on how three user companies benefited through the use of the company's electrodes and wires.

Reports describe how one company was able to fabricate a lightweight, mobile diesel pile hammer, with low-hydrogen electrodes, with a resultant strength equal to a cast or forged pile hammer; how stainless electrodes and wires were used to fabricate a "no margin for error" 34-ft pressure vessel for an AEC test reactor; and how a coal company is getting 400% longer life from hard surfacing material for bucket teeth.

For your free copy, circle No. 61 on Reader Information Card.

Dual Cleaning, Phosphating

A new, highly informative, 4-page booklet outlining the merits of Oakite CrysCoat 187, an iron phosphating material especially designed for simultaneous cleaning and phosphating by tank application, has just been released by Oakite Products, Inc., 157 Rector St., New York 6, N. Y.

Its chemical stability, positive corrosion control, long solution life and dual action of cleaning and phosphating are among the particular advantages cited for CrysCoat 187.

The booklet contains a technical product description, a brief method outline for applying the material and an insight into the simplicity of solution control which CrysCoat 187 affords.

For your free copy, circle No. 62 on Reader Information Card.

Strip Heaters Described

Full descriptions, illustrations and selection procedures for its line of general purpose and finned-type strip heaters are provided in a new 12-page, two-color catalog (C-300) now being offered by Bryant Electric Co., Bridgeport, Conn.

These strip heaters are suitable for heating ovens, process welding, outdoor control equipment, forced hot air heating, warming tables, process machinery, radiant heating and baseboard heating.

For your free copy, circle No. 63 on Reader Information Card.

Western Catalog Supplement

A special 4-page, 2-color, illustrated supplement to their 1961 Welding Connections Catalog has just been issued by Western Enterprises, Inc., Bay Village, Cleveland 40, Ohio, manufacturer of brass fittings for the welding trade.

New items introduced in the supplement are Hand-Tight Pigtail Assemblies for plant or filling stations, parts for Hand-Tight Manifold Assemblies, Copper & Stainless Steel Tubing for Manifold Assemblies, Special Regulator Adaptors, and Porous Metal Filters for Regulator Inlet Nipples.

For your free copy, circle No. 64 on Reader Information Card.

Heavy Duty DC Capacitors

A new 4-page catalog (No. 103) from Corson Electric Mfg. Corp., 540 39th St., Union City, N. J., describes capacitors for use in power supplies, voltage doubling circuits, communication receivers and transmitters, X-ray equipment, energy storage and other electronic applications. The literature describes how these capacitors may be used for high voltage filtering for 10,000 hr between −55 and +115° C. Ten different ranges are described from 10 to 60 KV DC.

BOUND VOLUMES . . .

of the 1960 Welding Journal now available at $20 per volume

Black cloth binding with gold lettering

Volumes for previous years also available in limited quantity

Write to: Welding Journal
345 E. 47th Street
New York 17, N. Y.

TUFFALOY forged seam welder wheels provide the utmost in conductivity and long life. Photo by Taylor-Winfield Corporation.

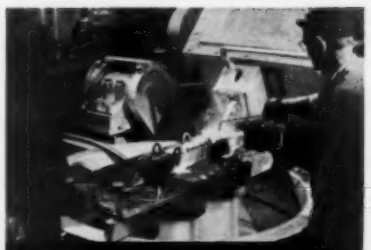
TUFFALOY FORGINGS

Fault-Free and Right on Spec

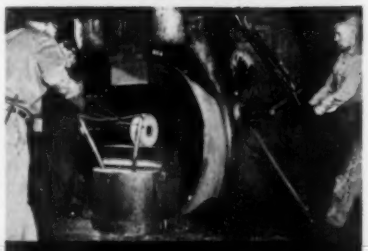
To carry the current they should and withstand the pressure they must, resistance welding alloy parts have to be right on specification both as to composition and structure.

RWMA specification forgings by TUFFALOY are used for seam welder wheels and shafts, butt and flash welder dies, and welding platens. TUFFALOY's more than twenty-five years in producing these forgings have led to the establishment of the largest stock of forged bars and wheels anywhere.

For fault-free forgings—wheels (finished or unfinished), square or rectangular bars, and special shapes of all kinds, all heat-treated or cold-worked to maximum hardness, specify TUFFALOY.



TUFFALOY alloys are semi-continuously cast into twenty-foot long billets for greater uniformity of structure.



Forging the desired shapes from heated segments of TUFFALOY billet under a steam hammer takes rare old-world skill.

Doc Tuffy says . . . to make sure every TUFFALOY forging meets hardness requirements, every forging is tested individually. TUFFALOY people will always go a step further to maintain product superiority.

Write or call your nearest AIRCO or TUFFALOY distributor. Ask whether your forging needs are now in stock. Ask him too for the TUFFALOY catalog . . . it makes correct alloy and tip specifications easy.

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For details, circle No. 33 on Reader Information Card

Graphs showing capacitance, dissipation and insulation resistance vs. temperature are provided to assist the designer, in addition to complete specifications, dimensions and operating characteristics.

For your free copy, circle No. 65 on Reader Information Card.

Water-Cooled A-C Compressor

Construction features and components of six-stage, single-casing, water-cooled centrifugal compressors (Type VC) are described in a new bulletin (16B9987) released by Chalmers, Milwaukee 1, Wis. The unit meets air applications requiring up to 15,000-cfm inlet volume at 100–125 psig.

The water-cooled centrifugal compressor has a horizontally split casing for quick accessibility of all parts; separate bearing housings for easy bearing inspection or maintenance; 10 interchangeable cooler bundles which can be cleaned without removing and removed without disturbing any other part of the unit.

For your free copy, circle No. 66 on Reader Information Card.

Tube Production Equipment

A new 34 page brochure in color is available from The McKay Machine Co., Youngstown, Ohio. Bulletin No. 107 illustrates and describes tube production equipment in all phases, coil handling, strip joining, strip guiding, strip forming, tube welding, oil cooled rotary transformer, tube finishing, tube cut-off, pipe mills, allied equipment and replacement rolls. Tube welding mills are available in 5 standard series.

As described in the brochure, continuous welding of the seam of the tube can be done by one of three systems—electric resistance, electric induction or shielded electric arc, each method particularly applicable to specific metal alloys and production requirements.

The welder section heats the seam edges to forging temperature and forces the edges together to weld the seam. Weld flash is then either rolled down or trimmed off, inside and out. Tooling is provided for guiding of the tube and disposing of the weld flash trimmings.

In addition to continuous cold roll formed tube making equipment, equipment is available for the manufacturing of spiral welded pipe, press-formed and welded pipe, and for processing, testing and fabricating pipe and tubing.

For your free copy, circle No. 67 on Reader Information Card.

Would you take a chance on a sure thing?

Make your next welder a P&H!

HARNISCHFEGER
Milwaukee 46, Wisconsin

P&H
WELDING PRODUCTS DIVISION

Fatigue-Proof Steel Bars

La Salle Steel Co., P. O. Box 6800-A, Chicago 80, Ill., has introduced the second in a series of case study portfolios on "Fatigue-Proof" Steel Bars.

The latest portfolio deals with the effect of "Fatigue-Proof" on end costs in typical parts applications.

For your free copy, circle No. 68 on Reader Information Card.

Proceedings of the Third Symposium on Electron Beam Processes. Edited by Robert Bakish, Hard Cover, 11 x 8½ in., 379 pp. Published by Alloyd Electronic Corp., Cambridge, Mass. Price $15.

This book contains a compilation of information on electron beam technology. There are 22 papers by scientists working in the forefront of electron beam technology covering the following areas: Physics of Electron Beams; Electron Beam Welding; On Less-known Electron Beam Applications; and Electron Beams in Microminiaturization.

Data for welding machine design, which is not readily available elsewhere, is presented in this volume.

There is a discussion of gun design, gun material limitations and other fundamental parameters in theoretical electron beam systems. Information obtained from studies with both high and low voltage systems is presented. In the unusual applications section, electron beams are discussed in relation to machining, electron beam recording and the role of electron beams as media for generating of radiation changes. Technological progress in such areas as microelectronics and related topics is also mentioned.

All you want—when you want it in the **RED DRUM.**
All sizes, in quantities from 2 lb. pkgs. to 5 ton hoppers.

Calcium carbide is a product of:

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A Division of Air Reduction Company, Incorporated
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For details, circle No. 34 on Reader Information Card

***The* FALSTROM**
Controlled angle torch

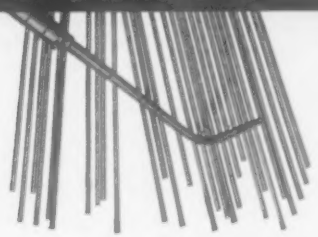
reduces costs!

The only tungsten inert gas, arc welding torch with complete flexibility. Split-second, hand adjustment to any angle . . . to suit job requirements or your own comfort. One torch does the work of many. Model WC-180 is rated at 180 amps, AC-DC. 12½', 25' and 50' hose lengths. Low first cost . . . low maintenance. Get the facts . . . ask for Bulletin WC-60.

FALSTROM COMPANY
222 Falstrom Court
Passaic, New Jersey
PRescott 7-0018

For details, circle No. 35 on Reader Information Card

TITAN quality metals for the welding industry



BRONZE WELDING RODS

Titan bronze welds are dependable in service, have high strength, toughness, excellent wear resistance. Welds are made easily and quickly to cast, malleable and wrought iron, most steels and many copper-base alloys. Because of their facility in permanent braze welding of so many metals, Titan welding rods are widely used in repair operations and in production welding of metal assemblies.

EXTRUDED BRASS SHAPES

Manufactured to your exact requirements, Titan special brass shapes give highest production, elimination of scrap parts and unsurpassed machinability.

BRASS & ALUMINUM FORGINGS

Hot-pressed to provide maximum density, high strength, long life, superior finished surface. Have thinner sections, closer tolerances and uniform free-machining advantages over sand castings.

BRASS & ALUMINUM MACHINED PARTS

Machining to close tolerances is a Titan specialty. You can cut costs and reduce assembly problems. Fast delivery is assured.

Established 1915

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RODS • FORGINGS • DIE CASTINGS • WELDING RODS • WIRE

Write for 6-page Welding Rod folder

For details, circle No. 36 on Reader Information Card

New Products

Integral Annealing System

A refined type of annealing system, now being introduced by Thomson Electric Welder Co., 161 Pleasant St., Lynn, Mass. features a circuitry arrangement that (1) automatically applies post heat to flash welds in green wire for an appropriate time interval and (2) permits accurate regulation of annealing temperatures by means of a pyrometer and a sensitive, manual feedback system located on the welding machine. Applied to a joint in green, high-carbon wire, the annealing operation produces characteristics in the weld identical to or better than the parent metal. Necking of the joint during wire drawing, a condition that occurs when the weldment is too soft, or cracking of the weld, caused by brittleness are reduced to infinitely small levels.

For details, circle No. 101 on Reader Information Card.

Wire Feed Unit

The Alloy Rods Co., P. O. Box 1828, York, Pa., recently announced a wire feed unit for semiautomatic open-arc hard surfacing by welding which provides $2^1/_2$ times the wire supply of the normal coil-type machine, with equal portability and weight. Combining the Weld-Pak as an integral part of the wire feed unit provides 125 lb of continuous welding wire, as opposed to the 50 lb coil of other type units. This feature cuts downtime for wire changeover by $^2/_3$, providing more time for welding.

The Model C Wear-O-Matic unit is for applications in hard to get at places, where a hoist is used to position the feed unit. The additional wire supply provided by the Weld-Pak means two less trips to the ground or work platform for new wire. Also, it eliminates the "short coil" loss which occurs when a partial coil is removed from a coil type machine and replaced with a full coil to accomplish a specific job.

For details, circle No. 102 on Reader Information Card.

Power Relay

A space-saving four-pole power relay that occupies approximately the same space as conventional 2-pole relays is available from Potter & Brumfield Div., American Machine & Foundry Co. Princeton, Ind. Over-all dimensions for the relay are: length—$3^{11}/_{32}$ in., width—$2^{41}/_{64}$ in., height—$2^1/_2$ in.

Designated the PM Series, this heavy-duty power relay is constructed for long life and dependability. It has a mechanical life in excess of 10 million operations at a maximum of two cycles per second with 50% dwell time. Rated load life is over 100,000 operations at a maximum of 14 cpm with 50% dwell time.

This relay is designed to meet Underwriters' Laboratories spacing and creepage requirements to 300 v for motor controllers of 1 hp or less.

For details, circle No. 103 on Reader Information Card.

Concentrates for Magnetic Particle Testing

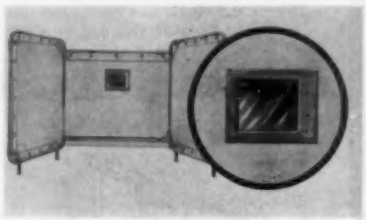
A complete new family of materials for the wet method of visible and fluorescent magnetic particle testing is now being introduced by Magnaflux Corp., 7300 W. Lawrence Ave., Chicago, Ill. This major development is the result of concentrated and continual research of a proved test method and magnetic particle pastes used throughout industry for over 30 yr to locate invisible cracks in ferrous material and parts.

The new materials, called concentrates, are all in powder form and incorporate features reportedly superior to the previous Magnaflux and Magnaglo pastes. Easier mixing, handling, and storage; a measurable increase in fluorescent brilliance from 70 to 600% closely controlled particle size range; less foaming; and more corrosion protection are reported.

For details, circle No. 104 on Reader Information Card.

Portable Screens with Glass Welding Plate

A glass welding plate is now available from the Singer Glove Manufacturing Co., 860 W. Weed St., Chicago 22, Ill., to solve the problem of viewing the welding operation safely. It can be used to good advantage for inspection or checking, for training purposes or when visitors arrive. The plate itself is filter shade #10 and is easily removed from its leather reinforced pocket. It is recommended when ordering Singer screens 6 to 8 ft high in either the triple or 4-sided models.



For details, circle No. 105 on Reader Information Card.

Power Line Filter

After some four years of development, new power line filters designed to provide levels of r-f suppression beyond any present filters are being manufactured by McMillan Industrial Corp., Brownville, Ave., Ipswich, Mass.

Model D-60, for example, is available for use on many types of industrial electrical equipment such as welders, X-ray equipment, transformers, diathermy and induction heating equipment, provides effective suppression of radio noise interference which many of these machines broadcast, according to McMillan. It has the following

For details, circle No. 38 on Reader Information Card ⟶

You can depend on

Tempilstik°

temperature indicating crayons

Each batch of Tempilstiks° is certified for melting point by our laboratory — and independently tested for accuracy by a distinguished firm of metallurgical chemists.

A PRODUCT OF AMERICAN INGENUITY

Tempilstiks° provide a simple and accurate means of determining preheating and stress relieving temperatures in welding operations. Tempilstiks° are widely used as a standard method of checking temperatures in all heat treating—as well as in hundreds of other heat-dependent processes in industry.

Available in 100 systematically spaced temperature ratings from 100° to 2500° F, inclusive.....$2.00 each.

Most leading welding supply houses carry Tempilstiks°. If yours is an exception, write to us for further information and the name of your nearest distributor.

ACCESSORIES DIVISION

Tempil° CORPORATION

132 West 22nd St., New York 11, N. Y.

Visit us at Booth 928—1961 ASM Show—Cobo Hall, Detroit, Mich., Oct. 23–27

Wallex Casting on Tail Skid Protects Navy Jet Fighter

When navy jets land on pitching ships, jet tails sometimes hit and scrape the deck. To protect both the aircraft and the deck, McDonnell puts smooth pads on the tail skids of its Demon jet fighter. Cast of wear-resistant Wallex alloy, these pads rebuff impact and corrosion, create little friction to mar flight decks.

Curved Wallex casting brazed to steel plate forms tail skid pad assembly.

As our example above shows, the proper functioning of a whole assembly can often be insured by protecting just one small area from damaging wear. Castings of various Colmonoy alloys are doing just that, in hundreds of places. Colmonoy nickel, cobalt, and iron-base alloys are also applied as welding rod, electrodes, paste, and as Sprayweld Powder. Learn more about this remarkable group of alloys.

Ask for Colmonoy Hard-Facing Manual No. 79.

HARD-SURFACING & BRAZING ALLOYS

WALL COLMONOY CORPORATION

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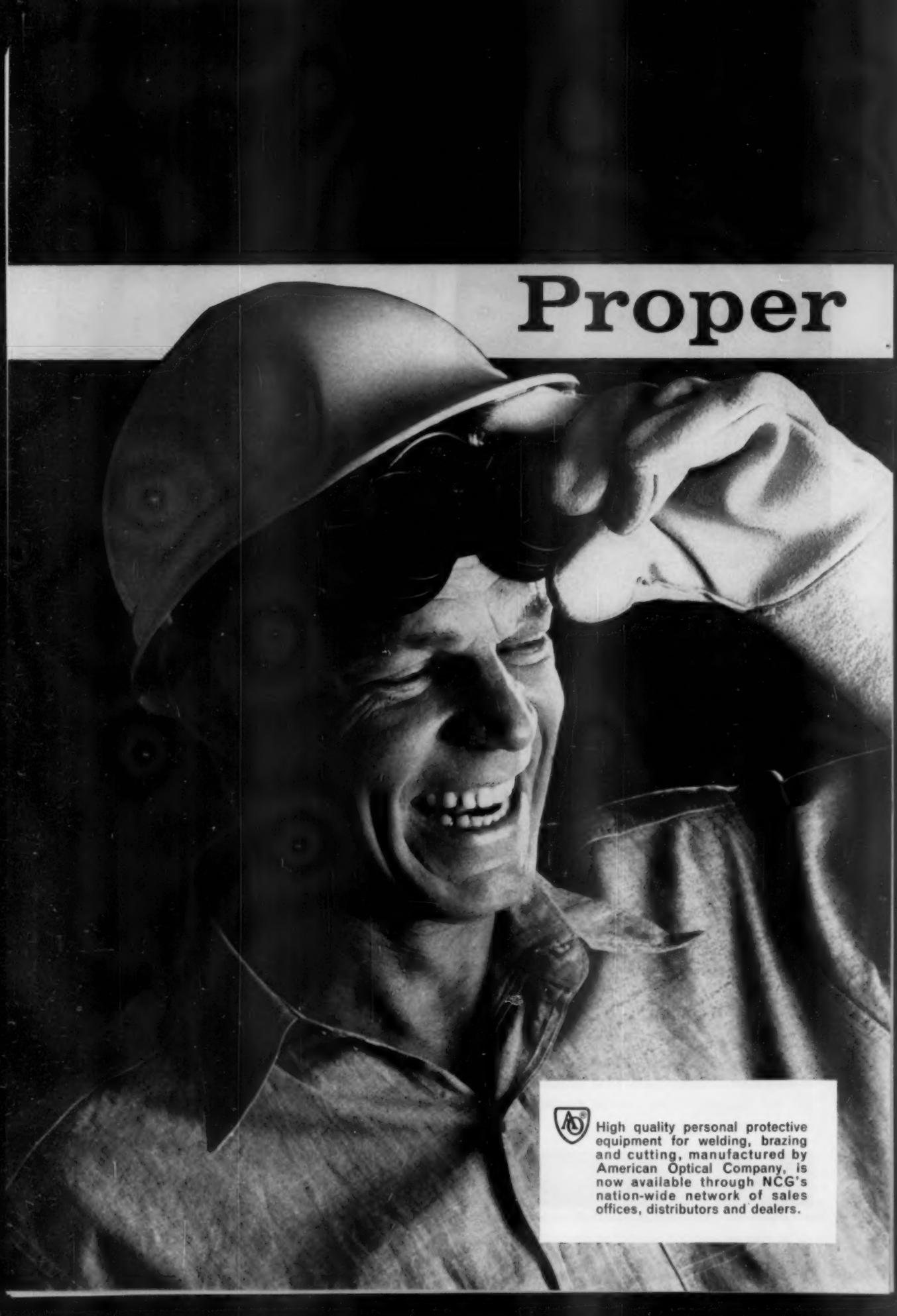
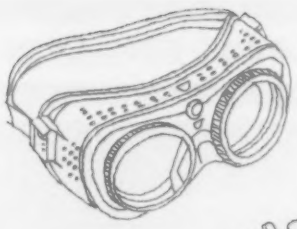
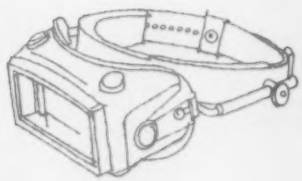
For details, circle No. 37 on Reader Information Card


Proper
High quality personal protective equipment for welding, brazing and cutting, manufactured by American Optical Company, is now available through NCG's nation-wide network of sales offices, distributors and dealers.





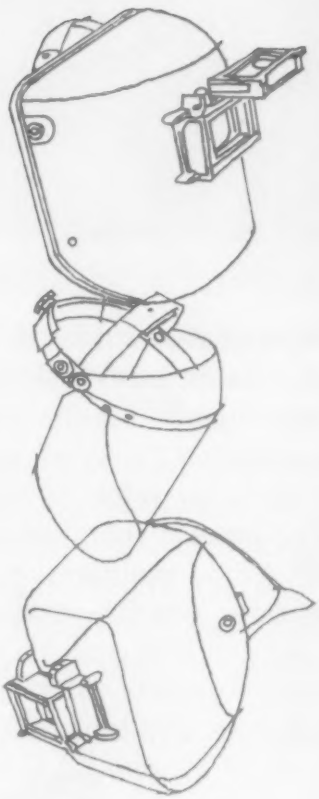
protection

keeps me happy

No one wants an accident—but just in case—*proper* protection, can prevent painful, costly injuries that often cause serious disabilities. Insurance does help, but no matter how much money is received as compensation, it is small return for the permanent damage that could have been avoided.

Your working skills and general well-being must be carefully protected. *Just any old* kind of protection won't do. Different jobs require different kinds of protection. The proper kind of protection for your welding, brazing and cutting jobs is available from your nearby NCG distributor or dealer. Send today for NCG Catalog N-177-E-1J.

NATIONAL CYLINDER GAS DIVISION OF
CHEMETRON CORPORATION,
840 North Michigan Avenue, Chicago 11, Illinois



NCG®

NATIONAL CYLINDER GAS

Division of CHEMETRON *Corporation*

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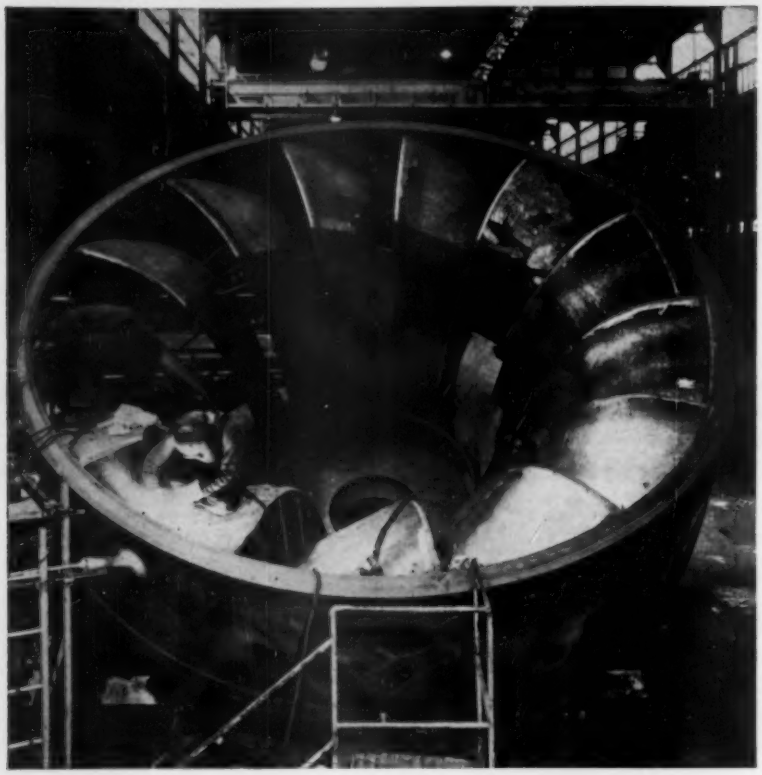
For details, circle No. 39 on Reader Information Card

WELD WITH ARCOS STAINLESS ELECTRODES



Job Report Courtesy of Allis-Chalmers Mfg. Co., Milwaukee, Wisconsin

Hydraulic turbine runner blades overlaid to resist cavitation. To protect the blades of this huge hydraulic turbine runner from the destructive effects of water wear, Arcos stainless rods were selected for overlaying critical areas. The precise chemical and metallurgical properties of Arcos stainless rods—assuring uniform, predictable results—make this process both dependable and economical. Meet your stainless welding requirements with Arcos—the most complete selection available anywhere.

ARCOS

Arcos Corporation • 1500 S. 50th St. • Philadelphia 43, Pa.

For details, circle No. 40 on Reader Information Card

characteristics: 50 amp at 250 vac, 400 cps; 60 amp at 250 vac, 60 cps; 70 amp at 600 vdc and 100 db+ from 100 kc to 45 kmc.

For details, circle No. 106 on Reader Information Card.

Sideshield for Safety Glasses

Willson Products, 212 E. Washington Ave., Madison 10, Wis., has introduced a new flat, half-type plastic sideshield in crystal clear or green for plastic safety glasses.

The new sideshields are cemented to temples and fit spatula or plastic-

cable styles. There is no need for a plastic flange on the eye wire, the way standard sideshields are attached. New Willson Clear-Vue sideshields available with Willson safety glasses or separately.

For details, circle No. 107 on Reader Information Card.

Rectangular Panel Meters

Design of a new line of all-metal panel meters has recently been completed by Helipot Div. of Beckman Instruments, Inc., 2500 Fullerton Rd., Fullerton, Calif.

These 4- x 6-in. rectangular meters are of all-metal construction with steel movement enclosures that protect fully against the effects of magnetic panel materials or stray RF. All meters in the series are gasket sealed to keep moisture, dirt and foreign particles out.

For details, circle No. 108 on Reader Information Card.

Gold Doping Technique for Transistors

The PADT-40, a switching transistor whose ultra-speed switching time results from a new technique whereby the collector region is gold doped for lower stored charge, has been announced by Amperex Electronic Corp., 230 Duffy Ave., Hicksville, L. I., N. Y.

A germanium PNP transistor, designed for high and medium speed saturated-logic applications, the PADT-40 has an average total switching time of 135 nanoseconds (td + tr = 50 nanosec; ts + tf = 85 nanosec), and a minimum time of 80 nanosec, measured in a conservative current driven saturated switching circuit. In voltage driven saturated switching circuits

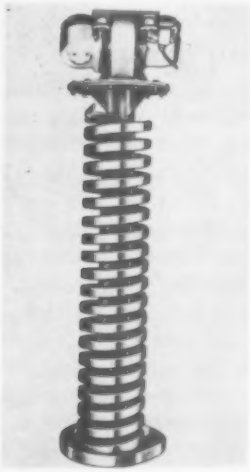
typical total switching times of 9 nanosec are readily obtainable.

For details, circle No. 109 on Reader Information Card.

New Spiral Feeder

A Spiral Feeder, powered by a rotary vibrator drive unit has been introduced by Syntron Co., 258 Lexington Ave., Homer City, Pa. This drive unit has a longer, more powerful stroke, enabling it to handle larger, higher spirals at greater capacities than the electromagnetic type, the company reports.

Among the many uses of Spiral Feeders are elevating metal parts



from cleaning and degreasing tanks, and stampings from presses to tote boxes, as well as handling most bulk materials. Economical and efficient cooling by convection or forced air is easily accomplished due to the maximum exposed area of the spiral ramp, in a minimum amount of floor area.

Three models are available with spiral heights from $3\frac{1}{2}$ to 20 ft. Syntron rotary vibrator Spiral Feeders operate on 230 or 460 v, 60 cycle, three phase ac.

For details, circle No. 110 on Reader Information Card.

Arc-welding Machines

Twentieth Century Manufacturing Co., 9250 Access Rd., Minneapolis, Minn., has recently announced the addition to their line of two new heavy-duty fan cooled 250- and 295-amp arc welders called the Models 41 and 42.

These new welders are said by the manufacturer to have been specially designed for the user who requires heavy-duty output but needs the economy of limited input.

BETTER STAINLESS WELDS WITH ARCOS

Arcos produces a full line of stainless filler metals...coated electrodes, bare electrode wire, consumable inserts, bonded fluxes. This across-the-board selection of filler metals, plus Arcos stainless welding know-how, assures you of the selection of the right filler metal for the most economical arc-welding process—manual, semi-automatic or automatic. Where you use Arcos stainless filler metals you build up the quality of your welds and push down your welding costs.

ARCOS

Arcos Corporation • 1500 S. 50th St. • Philadelphia 43, Pa.

For details, circle No. 41 on Reader Information Card

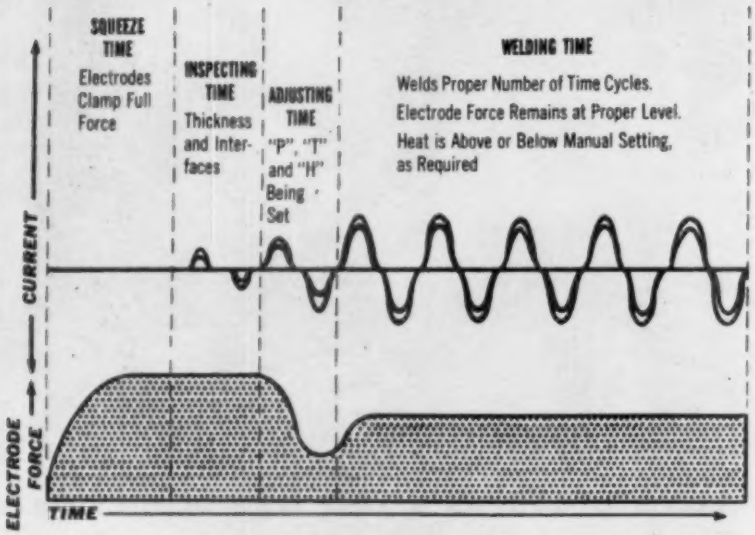
Weltronic® COMPANY presents

A new Weltronic Development:

PTH

the control that thinks for itself!

Automatically Adjusts Resistance Spot Welding Pressure, Time, and Heat Schedule!



HERE'S HOW IT WORKS:

Variations in welding conditions or materials change the welding circuit resistance, which is accompanied by a corresponding change in the welder secondary voltage. Pressure, time and heat are automatically and simultaneously controlled in accordance with welder secondary voltage. This is accomplished by sensing the secondary voltage and comparing it to a reference voltage, their difference indicating the extent of correction required. The voltage differential selects the proper operating pressure, heat setting, and welding time, as shown in the diagram at left.

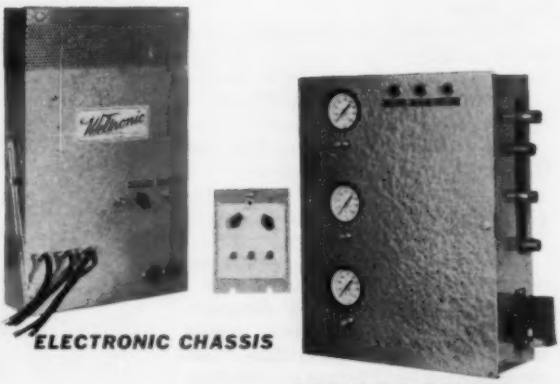
A control that does NOT try to change the rule that a good weld consists of the proper combination of pressure, time and heat.

A paper is to be presented on PTH Control at the
AMERICAN WELDING SOCIETY FALL MEETING
Dallas, Texas, September 28, 1961

Weltronic® COMPANY

19500 WEST EIGHT MILE ROAD
SOUTHFIELD, MICH. Phone KE 2-2800

World's Largest Manufacturer of
Electronic Resistance Welding Controls



ELECTRONIC CHASSIS

PRESSURE CHASSIS

This accessory can be added to current welding control now in the field

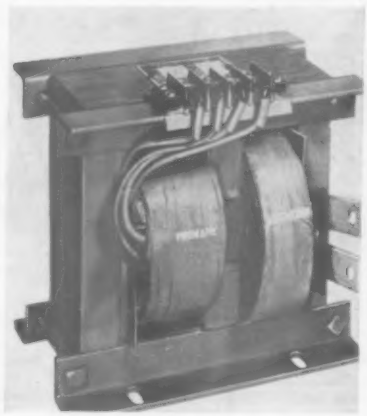
For details, circle No. 42 on Reader Information Card

Aside from amperage, other features of these welders are identical. They include: big inside mounted rubber tired wheels and tote-easy handle portability; easy-to-read precision dial control for fast simple amperage setting; a power packed transformer with precision wound copper coils over a laminated silicon steel core for easy starting and smoother operation; solid steel block type shunt which cannot burn or wear out, and the newest type polyester insulation for long life performance. The cooling fan develops forced air to dissipate heat and extend the life of the welder. Other features include dial light to eliminate the guess work in making amperage settings in dark places or during night work, and a separately fused 110 v power outlet which is handy when using drills, grinders and trouble lights.

For details, circle No. 111 on Reader Information Card.

Saturable Core Reactor

A new saturable core reactor is now available from Nothelfer Winding Laboratories, Inc., P. O. Box 455, Trenton, N. J. The core is wound with virtually no air gaps; this results in an extremely low magnetizing current and an unusually low noise output.



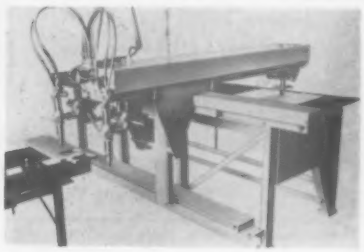
The range of the 15 kva, 1 ϕ saturable core reactor is approximately 2% to 98%, depending upon the resistive load.

For details, circle No. 119 on Reader Information Card.

New Oxyacetylene Cutter

An oxyacetylene machine which cuts any profile or design on metals according to drawings, templates or manual control, has just been introduced to the American market by G. L. Loos & Co., Fabrieken N.V., The Netherlands.

The front of the sheet-steel frame has rails for guiding the longitudinal slide which has a prismatically-cut large bearing surface on the main



FIRST IN . . . CAST IRON WELDING

The companion A. C. or D. C. electrodes . . . that handle with ease and deposit sound machinable welds . . . on ordinary cast iron special alloy irons or joining these irons to other metals.

Available in four standard diameters 3/32" — 1/8" — 5/32" and 3/16".

Contact your welding supply dealer, write or telephone us direct.

IMMEDIATE DELIVERY

ZENITH WELDING PRODUCTS COMPANY, Inc.

Area Code 201 CHestnut 5-3815

735 Lexington Ave. **P. O. Box 211** **Kenilworth, N. J.**

For details, circle No. 43 on Reader Information Card

rail. The length-wise slide also is immune from torsion or other movement, thus ensuring vibration-free functioning of the burners. Both the longitudinal and cross-slides run on adjustable ball bearings.

The cutting machine is driven by two commutator motors. The non-stepped variable cutting speed is adjusted by means of a push-button control device mounted on the side of the burners and at the rear of the machine. Turns of up to 145 deg can be carried out.

Machine controls are topped off by four switches: One for the current supply, one for switching on the electromagnet for the template scanning, one for changing over the motor to forward and reverse, and the last for operating the electromagnetic solenoid valve to open and close the oxygen feed.

For details, circle No. 112 on Reader Information Card.

High-Speed Grinders

New lightweight, high-speed Series 15 air driven grinders reduce production time, minimize operator fatigue and provide easy access to all areas of the workpiece in metal grinding or buffing, according to their manufacturer, Ingersoll-Rand, 11 Broadway, New York 4, N. Y. The 12 new grinders measure only

FOR ALL YOUR BRAZING ALLOY NEEDS

Low Fuming Bronze
Nickel Silver
Silver Solder
Phosphor Copper
Phosphor Silver
Silicon Bronze
Nickel Bronze
Aluminum Welding Wire

Alloys meet AWS, ASTM & Govt. Specs.

For This Free Catalog and Name of Nearest Distributor Write:

American Brazing Alloys Corp.
Pelham, N. Y.
Tel: MOunt Vernon 4-5858

For details, circle No. 45 on Reader Information Card

WE HAVE THE FLUX RIGHT For Your Job

66 years of experience in scientific development in welding

Whatever the particular job you have to do—we have the right FLUXINE you need. Besides our 25 FLUXINES we carry a complete line of "KOP-R-ARC" coated rods for welding copper and all copper alloys.

Write on company letterhead for chart and generous sample stating which FLUXINE desired.

KREMBS & COMPANY
(Est. 1875)
Dept. W, 669 W. Ohio St., Chicago 10, Ill.

For details, circle No. 46 on Reader Information Card

SALES REPRESENTATIVE

Hard Facing Materials

Unusually attractive opportunity is available for an experienced hard facing materials sales representative with a leading manufacturer of welding materials located in the Eastern U. S.

The man we are seeking must have 7–15 years broad experience handling diversified line of hard surfacing materials and be thoroughly familiar with their specific applications. He must also have the ability to demonstrate our products.

Remuneration will be on a salary + commission basis.

Send complete confidential resume including salary requirements to:

Box WJ 647, 125 W 41 St, N Y 36.

NEW RODS
NEW LOW PRICES
NEW "TUFF-TOP"

MOLY-NICKEL Hard Facing Fuse-Well No. 16 Rods

- NICKEL-COPPER Fast-Flow Fuse-Well No. 66 Rods
- No. 22 Dual Purpose Cast Iron Electrodes

WRITE FOR SAMPLES, NEW LOW PRICES TODAY!

Weld Rod Division
CHICAGO HARDWARE FOUNDRY CO.
North Chicago, Illinois

FUSE WELL

For details, circle No. 47 on Reader Information Card

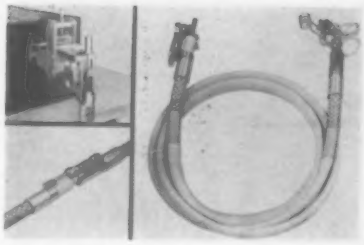
16⅝ to 18-in. long and weigh 6½ to 7¼ lb. The high speed tools have free speeds of 6000, 9000, 12,000, 15,000 rpm, providing rapid finishing and minimizing job time. A choice of grip or straight handles and thumb or lever throttles provides easy handling on a variety of jobs. A wide selection of equipment for using a variety of wheels with these tools gives the user practically a custom-designed tool for his particular operations, which can still be readily modified for other use.

For details, circle No. 113 on Reader Information Card.

Heavy-Duty Coaxial Cable

The L. C. Miller Co., 717 Monterey Pass Rd., Monterey Park, Calif. has introduced a new heavy-duty coaxial cable for use with the Miller Re-Coil on high frequency induction heaters.

These cables have been instrumental in the development of induction heating techniques, particularly in places formerly inaccessible. Applications now possible include brazing of tube joints inside airframes, missiles and submarines; also soldering, heat treating, annealing, zone refining, high temperature tensile testing and hot machining of space-age alloys.



Although flexible, the cable is rugged and wear-resistant; and contains the circulating water cooling courses for the work coils. Heater output may be controlled by any of several methods: a hand-grip, foot pedal or automatic timer.

For details, circle No. 114 on Reader Information Card.

Visitor Spec Dispenser

Willson Products, Second & Washington Sts., Reading, Pa., has introduced its exclusive, attractive, free Visitor Spec dispenser in Willson green, white and black. It holds 12 pair of Willson VS3 Visitor Specs.

Equipped to hang on gate house—set on desk or table, dispenser has tear out section at bottom for dispensing individually polyethylene

IMPORTANT ANNOUNCEMENT

The Welding Journal and other AWS departments have moved to the new United Engineering Center. Communications should thus be addressed to the Welding Journal or American Welding Society at:

United Engineering Center
345 E. 47th Street
New York 17, N.Y.

Telephone Number:
Plaza 2-6800

YOU GET MORE
WITH A MILLER

The practical limits of perfection in d-c welding, as such limitations are assessed today, are attained in Miller Gold Star welders with their exclusive, completely sealed, semi-metallic rectifiers.

Top illustration—the SR—comes in four basic models of from 200 to 600 amperes, with duplex hook-ups rated to 1200 amperes.

The space-saving SRH is only 30¼" high and is used widely for stacking and paralleling where room is at a premium. This model is offered in 200, 300 and 400 amperes.

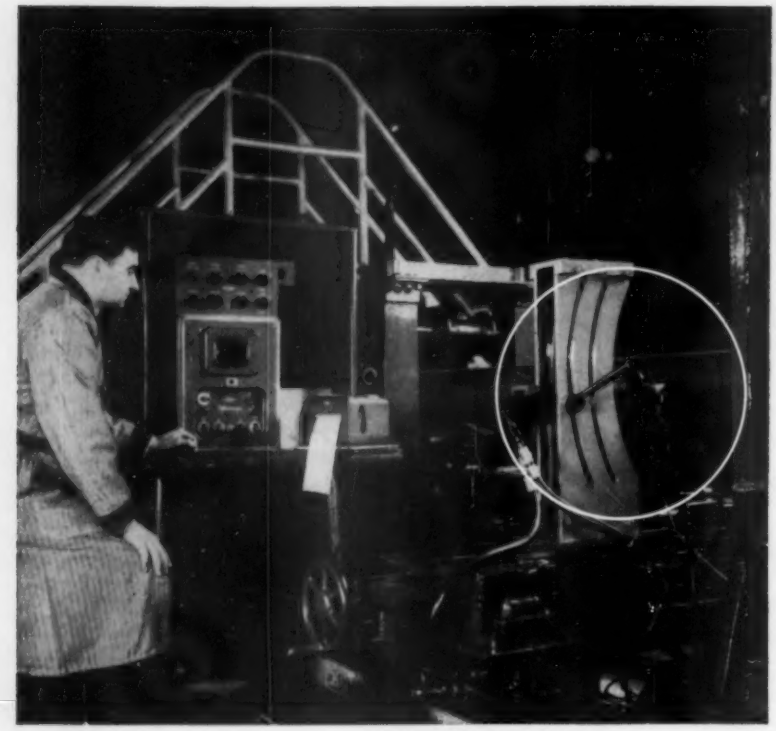
Complete particulars on the above welders will be sent promptly upon request. Also available is a frank and interesting pamphlet titled "Rectifiers for Welding," which gives a question and answer treatment to the established facts of welder rectifiers.

MILLER ELECTRIC MANUFACTURING COMPANY
APPLETON, WISCONSIN

EXPORT OFFICE: 3 West 57th St., New York 19, N.Y.

Distributed in Canada by
Canadian Liquid Air Co., Ltd., Montreal

For details, circle No. 48 on Reader Information Card



Sperry Ultrasonic Inspection at 150 feet per minute...

assures pipe weld quality

Sperry ultrasonic engineers, located in all major industrial areas are available for consultation on your automated or manual testing problems.

Call on Sperry experience and research for a solution.

The weld in line pipe for the oil and gas industry must not fail. Yet speed of production also remains an economically important must.

Sperry engineers, working with Jones & Laughlin production engineers, developed a method of integrating the necessary ultrasonic weld inspection into the J & L 150-feet-per-minute electricweld production line.

In operation, the Sperry angle beam search head contacts the pipe as it moves through the mill, and all defect indications are monitored by a Sperry R.A. unit to flash a light, to relay the signal of the defect to a pen recorder and to actuate controls to dye mark the flaw area.

Sperry Products Company

DIVISION OF HOWE SOUND COMPANY

2409 Shelter Rock Road, Danbury, Connecticut

For details, circle No. 50 on Reader Information Card

bagged visitor specs one at a time. Pull-out strip on side indicates number of specs remaining in dispenser.

Simple to reinsert specs where visitor's specs are reissued. Keeps specs clean and factory fresh.

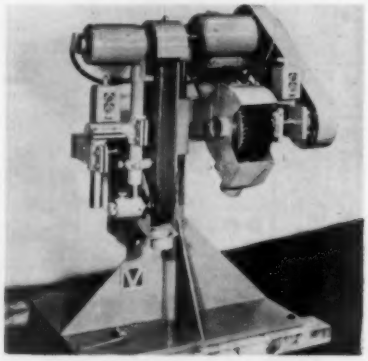
Improved Willson Visitor specs are comfortable, lightweight, economical, have good optical qualities and feature highly impact resistant lenses. They fit over any size prescription glasses.

For details, circle No. 115 on Reader Information Card.

Grinding, Finishing Machine

A new combination grinding and finishing machine for multipurpose operation has been designed and built by Grinding and Polishing Machinery Corp. 2530 Winthrop Ave., Indianapolis 5, Ind.

This unit features a 2 hp abrasive belt grinder with contact wheel and platen for quick stock removal and a



Vonnegut Brush-backed Polishing Head for smoothing and blending to proper finish.

The universal adjustment of the belt unit permits tilting to grind on the contact wheel.

For details, circle No. 116 on Reader Information Card.

Carryable 180-Amp Welder

A new "Compact" (1 cu ft) AC welder weighing only 65 lb, with 6 steps of heat from 60 to 180 amp, is announced by Harnischfeger Corp., Milwaukee, Wis.

It is offered *only* as a ready-to-use-kit, complete with electrode cable and holder, ground cable with

clamp, welding helmet, wall outlet and package of electrodes.

Operating on 230 v, 50 or 60 cycle, single phase current, with a full input load of 37 amp, the "Compact" is a full-fledged arc welder, equal to all jobs within its capacity. A high open circuit voltage of 70 v permits welding with low hydrogen and stainless steel electrodes up to $^{3}/_{16}$ in. It meets all NEMA, UL and REA specifications.

For details, circle No. 117 on Reader Information Card.

New Layout Tool

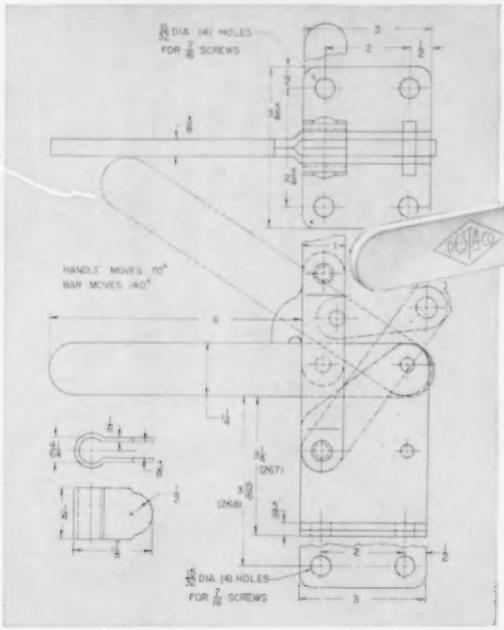
A new layout tool offering unusual accuracy to plus or minus 0.005-in. has been introduced by O'Brien Engineering Co., South Beloit, Ill.

The Micro-Layout Tool is designed for use in scribing straight

lines or circles for the sheet metal, pattern making, welding, metal fabricating, agricultural, woodworking and construction industries.

For details, circle No. 118 on Reader Information Card.

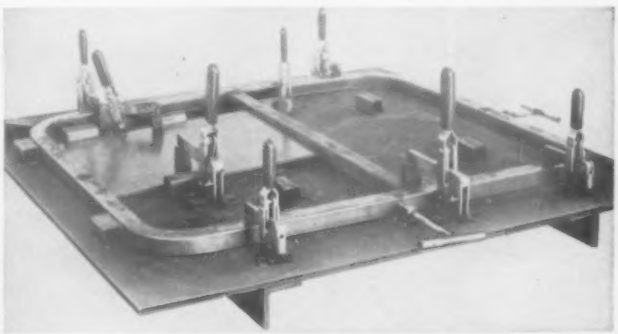
YOU *CAN* HAVE PRE-PLANNED PRODUCTION



DE-STA-CO

WITH DE-STA-CO TOGGLE CLAMPS

De-Sta-Co makes it easy to pre-plan production jigs and fixtures right on the drawing board! Detailed tracing templates, in full and half size, can be slipped under a drawing and spotted accurately—saves design time, speeds fabrication! Choose from over 140 models, there's a clamp for every job.



Steel welding fixture with 8 De-Sta-Co Model 267 Toggle Action Clamps holds parts securely during fabrication.

HOLDING PRESSURES FROM MERE OUNCES TO 16,000 POUNDS
FOR DETAILS—ASK FOR NEW 36-PAGE CATALOG

TOGGLE CLAMPS
SHIMS AND SPACERS
DE-STA-CO
STAMPINGS
BLOWER HOUSINGS

DETROIT STAMPING COMPANY
340 MIDLAND AVENUE • DETROIT 3, MICHIGAN
For details, circle No. 51 on Reader Information Card

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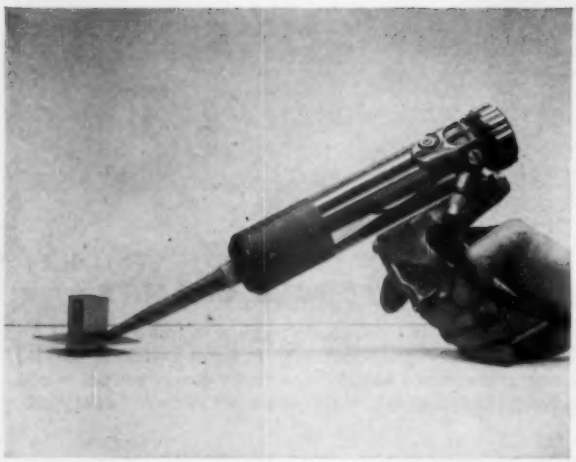

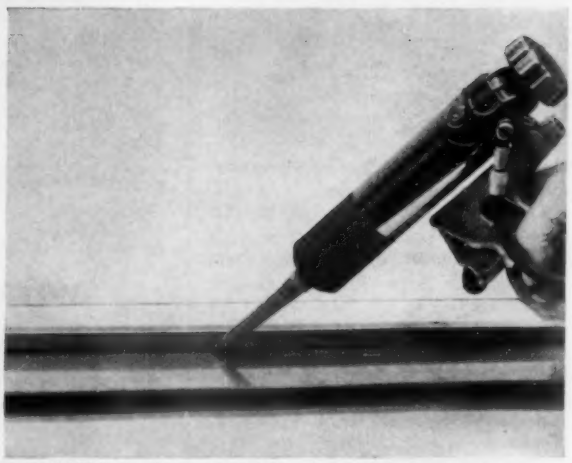

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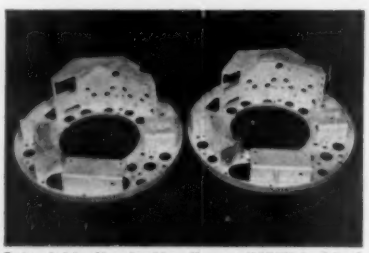

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8	33	58	83	108	133
9	34	59	84	109	134
10	35	60	85	110	135
11	36	61	86	111	136
12	37	62	87	112	137
13	38	63	88	113	138
14	39	64	89	114	139
15	40	65	90	115	140
16	41	66	91	116	141
17	42	67	92	117	142
18	43	68	93	118	143
19	44	69	94	119	144
20	45	70	95	120	145
21	46	71	96	121	146
22	47	72	97	122	147
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5	30	55	80	105	130
6	31	56	81	106	131
7	32	57	82	107	132
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11	36	61	86	111	136
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17	42	67	92	117	142
18	43	68	93	118	143
19	44	69	94	119	144
20	45	70	95	120	145
21	46	71	96	121	146
22	47	72	97	122	147
23	48	73	98	123	148
24	49	74	99	124	149
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SUPPLEMENT TO THE WELDING JOURNAL, SEPTEMBER 1961

Study of the Causes of Cracking in Submerged-Arc Welds in Constructional Alloy Steels

Less than 0.030% sulfur and phosphorous has no effect on submerged-arc weld hot-crack sensitivity, although more than 0.020% sulfur and phosphorus affects hot-crack sensitivity of T-1 steel

BY M. D. RANDALL, R. E. MONROE AND H. J. NICHOLS

ABSTRACT. A research program was conducted to study the causes of cracking in submerged-arc welds deposited in constructional alloy steels. This program was prompted by cracking of an unknown nature that occurred in a large structure. The program as described here was only to be concerned with the possible cracking that would occur at high temperatures.

Freezing-cycle hot-tension tests and restrained-weld cracking tests were made on experimental heats of steel. The heats were similar in composition to the weld metals used to join both "T-1" constructional alloy steel members and United States Steel Corp. TRI-TEN steel members. These studies were made to determine the effects of sulfur and phosphorus (in combination), manganese, silicon and aluminum on the hot-cracking tendencies of the steels.

Although the type, size and distribution of sulfide inclusions appear to have a marked influence on hot-cracking sensitivity, the results of this investigation indicate that heats with compositions approximating weld metals in "T-1" and TRI-TEN steels are not susceptible to hot cracking with sulfur and phosphorous contents up to 0.030 wt-% each.

M. D. RANDALL is Principal Welding Engineer, and R. E. MONROE is Assistant Chief, Metals Joining Division, Battelle Memorial Institute, Columbus, Ohio; H. J. NICHOLS is Chief Research Engineer, Metals-Joining, Applied Research Laboratory, U. S. Steel Corp., Monroeville, Pa.

Paper to be presented at AWS National Fall Meeting to be held in Dallas, Tex., Sept. 25–28, 1961.

Introduction

The use of heat-treated constructional alloy steels has increased rapidly in the past few years. These steels are finding useful application in construction of bridges, pressure vessels and transportation equipment. In general, these materials have good weldability. However, some difficulties with weld-metal and heat-affected zones have been encountered. Research effort such as that described in this paper is continuing in an effort to eliminate even these difficulties.

During the erection of a welded bridge, some members fabricated from heat-treated constructional alloy steel by welding were found to contain weld-metal cracks.[1] These cracks were repaired immediately by manual-arc welding. Thus, samples could not be obtained to determine the nature of the cracking. The program described here was undertaken to study the possibility that hot cracking had contributed to the formation of these defects. The members containing cracks had been fabricated by the submerged-arc welding process. Therefore, research was limited to welds of this type and included studies of compositional variables of weld metals that are encountered in fabrication.

Studies of the effects of composition of weld metals were made using freezing-cycle hot-tension tests restrained-weld cracking tests, and metallographic techniques. These studies were made on experimental steel heats with varying compositions.

Materials

Eighteen experimental induction-furnace heats of steel were prepared for this investigation. The chemical compositions of these steels approximated those of (*a*) "T-1" steel base plate, (*b*) weld metal of the composition used to join "T-1" steel bridge members (hereinafter referred to as Type 1 composition) and (*c*) weld metal of the composition used to join TRI-TEN steel members in the same bridge (hereinafter referred to as Type 2 composition). These heats were

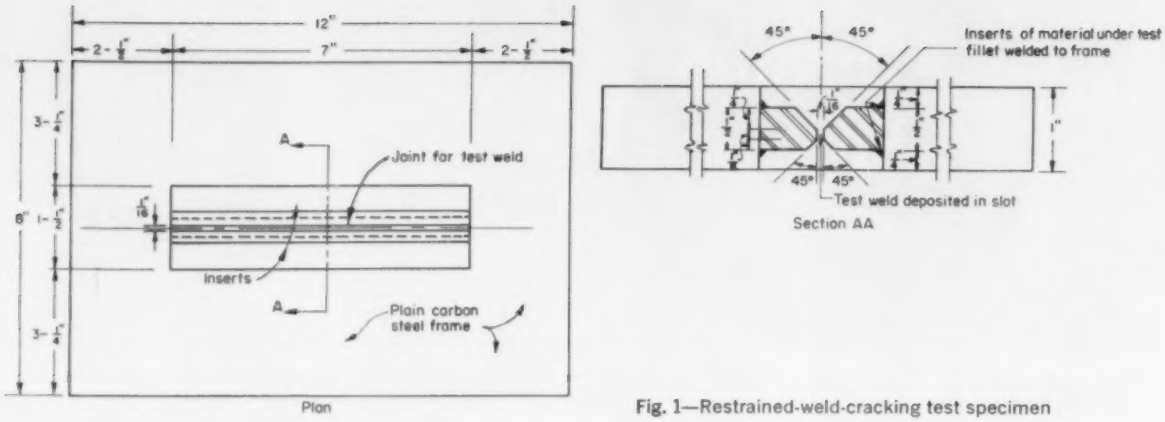

Fig. 1—Restrained-weld-cracking test specimen

used to study the effects of sulfur and phosphorus (joint), various manganese-silicon ratios, and soluble aluminum on the high-temperature strength and ductility of these steels. The analyses of the heats are given in Table 1. Generally, split heats were used to produce a base composition with varying sulfur and phosphorus or varying aluminum contents. In all cases, 37-lb ingots were poured. These ingots were forged and hot-rolled to 3/4 in. diam bars in preparation for machining freezing-cycle hot-tension test specimens.

Filler wires for welding were processed from the experimental heats of steel. These wires were hot-rolled and drawn to 0.102 in. diam for use in the submerged-arc welding processes.

Experimental Procedure

Two techniques were used to evaluate the hot-cracking sensitivity of the alloys tested: (*a*) freezing-cycle hot-tension tests and (*b*) restrained-weld cracking tests. These techniques are described below under separate headings.

Freezing-cycle Hot-tension Tests

The freezing-cycle hot-tension test is used to determine the strength and ductility of a freezing metal under thermal conditions simulating welding. Details of the technique and descriptions of the equipment have been presented in the literature.[2-4] In this work, approximately 15 specimens were machined from each heat of steel.

Specimens were tested over the temperature range from 2700 to 1800° F during cooling from the molten state.

Reduction of area of the specimen was used as a measure of the hot ductility. The final average diameter was determined from multiple measurements on each end of the fractured specimen. Strength and reduction of area vs. testing temperature plots were made for each heat of steel studied. The shapes of the curves were used to evaluate the relative hot-cracking sensitivities of the various heats.

Table 1—Analyses of Experimental Heats of Steel

		Chemical composition, wt-%													
Heat[a]	Heat number	C	Mn	Si	S	P	Ni	Cr	Mo	Cu	B	V	Soluble Al	Insoluble Al	N_2	Mn-Si Ratio
AA	B-6043-1	0.17	0.90	0.23	0.006	0.008	0.83	0.49	0.44	0.31	0.0024	0.05	0.068	0.015	0.005	3.91
AB	B-6043-2	...	...	...	0.015	0.016	...	...	...	...	...	...	...	...	...	...
AC	B-6043-3	0.17	0.89	0.23	0.028	0.029	...	...	...	...	...	...	...	...	...	3.87
JA	B-6352-1	0.17	0.90	0.30	0.033	0.028	0.80	0.49	0.44	0.36	0.003	0.06	0.002	0.015	0.003	3.00
JB	B-6352-2	...	...	...	...	...	...	...	...	...	...	...	0.011	0.015	...	...
JC	B-6352-3	...	...	...	...	...	...	...	...	...	...	...	0.033	0.010	...	...
BA	B-5952-1	0.13	1.06	0.63	0.008	0.007	0.30	0.21	0.58	0.25	0.0022	0.02	0.058	0.012	0.011	1.68
BB	B-5952-2	...	...	...	0.022	0.021	...	...	...	...	...	...	...	...	...	...
BC	B-5952-3	0.13	1.07	0.63	0.032	0.029	...	...	...	...	...	...	...	...	...	1.70
CA	B-5884	0.13	1.25	0.61	0.021	0.025	0.35	0.23	0.61	0.28	0.0018	0.03	0.057	0.007	0.010	2.05
CB	B-5894	0.12	0.83	0.60	0.024	0.024	0.34	0.20	0.60	0.27	0.0021	0.02	0.058	0.019	0.007	1.38
CC	B-5895	0.12	0.84	0.7	0.022	0.024	0.35	0.23	0.62	0.28	0.0021	0.02	0.042	0.016	0.008	1.08
DB	B-5885-3	0.13	1.00	0.70	0.021	0.024	0.34	0.21	0.60	0.28	0.0013	0.03	0.068	0.016	0.007	1.43
DA	B-5885-1	0.14	1.01	0.50	0.022	0.024	0.34	0.23	0.62	0.28	0.0014	0.03	0.073	0.020	0.007	2.02
DC	B-6044	0.14	1.02	0.37	0.018	0.020	0.39	0.22	0.49	0.26	0.0016	0.03	0.026	0.013	0.011	2.76
EA	B-5950-1	0.15	1.41	0.64	0.008	0.005	...	...	0.40	0.24	...	0.02	<0.005	0.026	0.009	2.20
EB	B-5950-2	...	...	...	0.022	0.017	...	...	...	...	...	...	...	...	...	...
EC	B-5950-3	0.15	1.41	0.64	0.030	0.026	...	...	...	...	...	...	...	...	...	2.20

Heats AA, AB, and AC, steel of composition of "T-1" steel having three sulfur and phosphorous levels. Heats JA, JB, and JC, steel of composition of "T-1" steel having three soluble aluminum levels. Heat BA, BB and BC, Type 1 weld metal having three sulfur and phosphorus levels. Heats CA, CB and CC, Type 1 weld metal having two manganese levels and three manganese-silicon ratios. Heats DA, DB and DC, Type 1 weld metal having three different manganese-silicon ratios at constant manganese level. Heats EA, EB and EC, Type 2 weld metal having three sulfur and phosphorus levels.

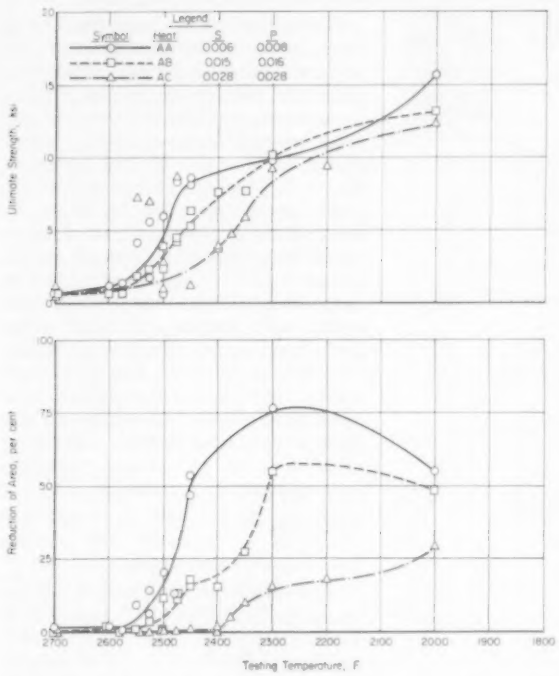

Fig. 2—The effects of sulfur and phosphorus on the high-temperature strength and ductility of steel of "T-1" composition

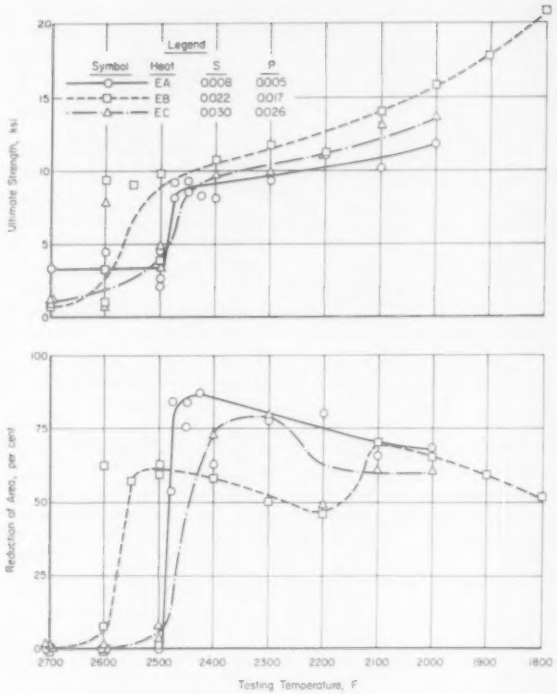

Fig. 4—The effects of sulfur and phosphorus on the high-temperature strength and ductility of Type 2 weld-metal composition

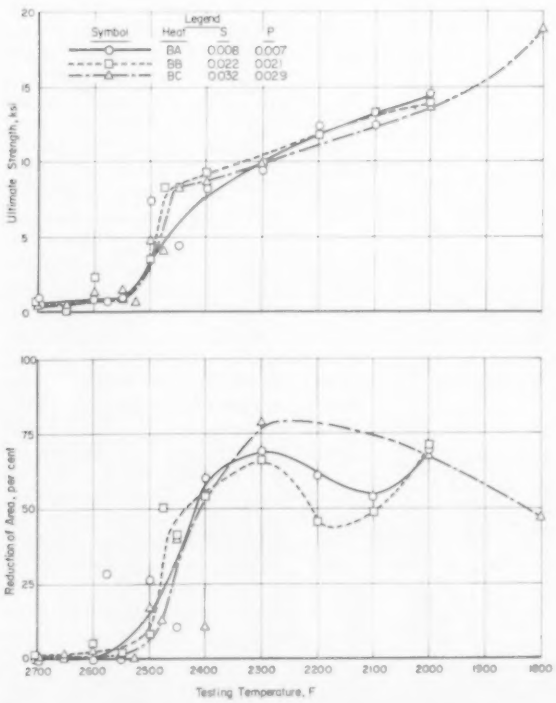

Fig. 3—The effects of sulfur and phosphorus on the high-temperature strength and ductility of Type 1 weld-metal composition

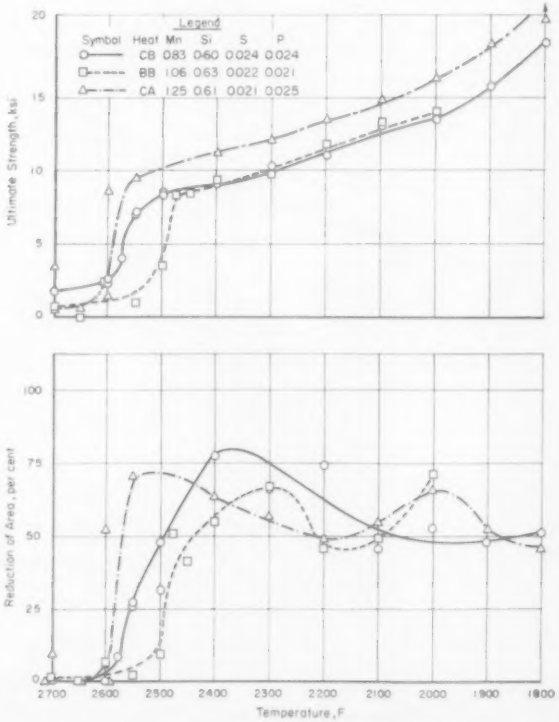
Legend
Symbol Heat Mn Si S P
CB 0.83 0.60 0.024 0.024
BB 1.06 0.63 0.022 0.021
CA 1.25 0.61 0.021 0.025
Ultimate Strength, ksi
Reduction of Area, per cent
Temperature, F

Fig. 5—The effects of manganese with constant silicon content on the high-temperature strength and ductility of Type 1 weld-metal composition

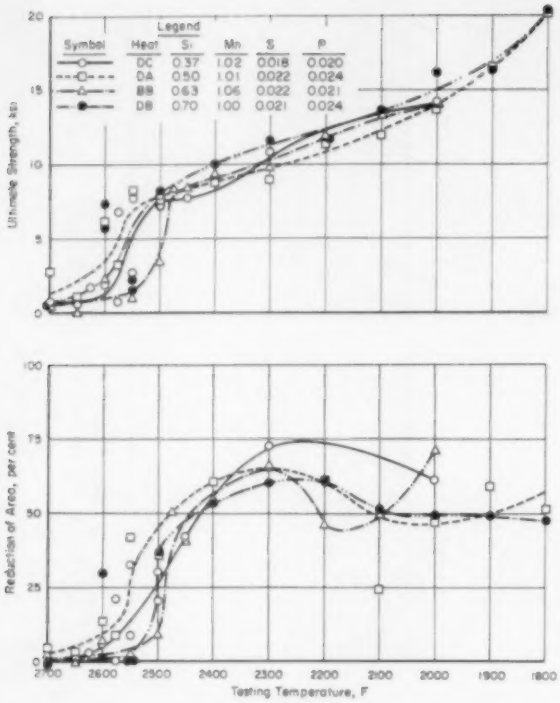
Legend
Symbol Heat Si Mn S P
DC 0.37 1.02 0.018 0.020
DA 0.50 1.01 0.022 0.024
BB 0.63 1.06 0.022 0.021
DB 0.70 1.00 0.021 0.024
Ultimate Strength, ksi
Reduction of Area, per cent
Testing Temperature, F

Fig. 6—The effects of silicon with constant manganese content on the high-temperature strength and ductility of Type 1 weld-metal composition

Restrained-weld Cracking Tests

Restrained-weld cracking tests were made as another measure of hot-cracking sensitivity. The test specimen used is shown in Fig. 1. Inserts prepared from several of the experimental heats were fillet-welded to the sides of the slotted frame as shown in Fig. 1. Single-pass test welds were deposited by the submerged-arc process with filler wires made from the experimental heats. No preheat or postheat was used in depositing these welds. The test welds with inserts machined from the experimental heats were radiographed as soon as the weld had cooled to room temperature and then were allowed to remain in the frames for at least 24 hrs. After this elapsed time, the welds were examined visually for cracks.

Test Results

Freezing-cycle Hot-tension Tests

The relationships between tensile strength, reduction of area, and testing temperatures are shown in Figs. 2 through 8. The results of these tests are summarized below:

1. Increasing sulfur and phosphorus from 0.006 and 0.008, respectively, to 0.028 and 0.029 wt-% greatly reduced the hot ductilities of

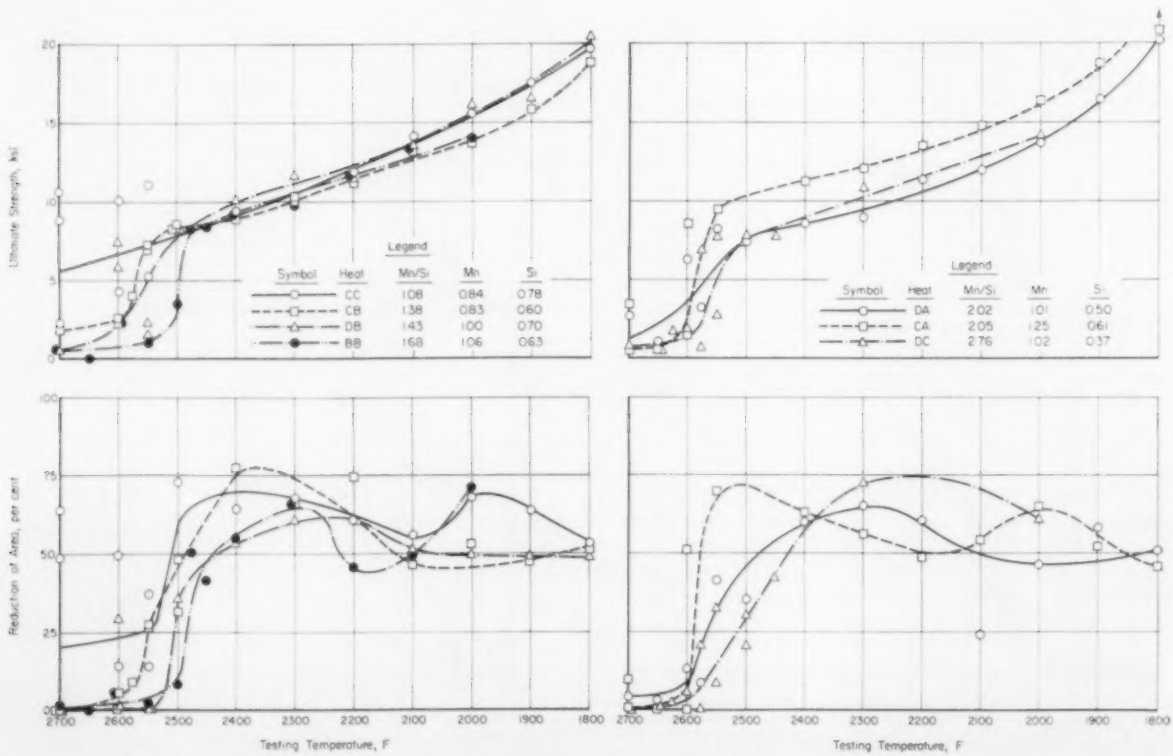

Fig. 7—The effects of manganese-silicon ratio on the high-temperature strength and ductility of Type 1 weld-metal composition

the experimental heats of steel of "T-1" composition (Heats AA, AB and AC in Fig. 2). The hot ductilities of Type 1 weld-metal compositions (Heats BA, BB and BC in Fig. 3) and Type 2 weld-metal compositions (Heats EA, EB and EC in Fig. 4) were *not* reduced by increasing sulfur and phosphorus contents over the same composition range. The effect of increasing sulfur and phosphorus on the hot strengths of the heats of steel of "T-1" composition was to lower the temperature at which strength began to develop. The hot strengths of Type 1 and Type 2 weld metals were unaffected by increasing sulfur and phosphorus contents over the same composition range.

2. Variations in the manganese and silicon contents with a medium sulfur and phosphorus level in Type 1 weld-metal compositions (Heats CB, BB and CA in Fig. 5; Heats DC, DA, BB and DB in Fig. 6) had no consistent effect on the strength and ductility determined in this test. The resulting variations in the manganese-silicon ratios of these steels (Heats CC, CB, DB, BB, DA, CA and DC in Fig. 7) also could not be related to the properties measured in these tests.

3. Increasing the soluble aluminum content from 0.002 to 0.068 wt-% of heats of steel of "T-1" composition (Heats JA, JB, JC and AC in Fig. 8) had little consistent effect on the high-temperature strength and ductility of these heats. The hot ductility of all these heats was very poor regardless of the soluble aluminum content. However, Heat AC with a soluble aluminum content of 0.068 wt-% had the poorest hot strength and hot ductility.

Representative freezing-cycle hot-tension test specimens of some of the heats were examined metallographically to identify the types of sulfide inclusions present. Considerable research has been done to relate types of sulfide inclusions to room- and elevated-temperature mechanical properties. Sulfides are classified by their shapes: Type I, globular, Type II, film or continuous grain-boundary network; and Type III, angular. The least harmful are the angular Type III inclusions. The sulfide inclusions most damaging to the mechanical properties of steel and those that are most generally associated with high-temperature cracking are the network or stringer Type II inclusions. The sulfide inclusions in the specimens examined were identified only as to type, as described

Table 2—Identification of Sulfide Inclusions in Freezing-cycle Hot-tension Test Specimens

Heat or specimen identification	Composition	Identification of sulfide inclusions
AA	Low S and P experimental heat of "T-1" composition	Few sulfides, mostly Type I, trace of Type II
AC	High S and P experimental heat of "T-1" composition	Numerous sulfides, mostly Type II
BA	Low S and P experimental heat of Type 1 weld metal	Very few sulfides, most of which are Type I, trace of Type II
BC	High S and P experimental heat of Type 1 weld metal	Fewer sulfides than in Heat AC, most of which are fine and scattered Type II with a few Type I
JA	High S and P experimental heat of "T-1" composition with soluble aluminum, 0.002%	Medium quantity of sulfides, mostly Type I, trace of Type II
JB	High S and P experimental heat of "T-1" composition with soluble aluminum, 0.011%	Numerous sulfides, mostly Type II, few Type I
JC	High S and P experimental heat of "T-1" composition with soluble aluminum, 0.033%	Fewer sulfides than Heats JA and JB, mostly Type II, few Type I

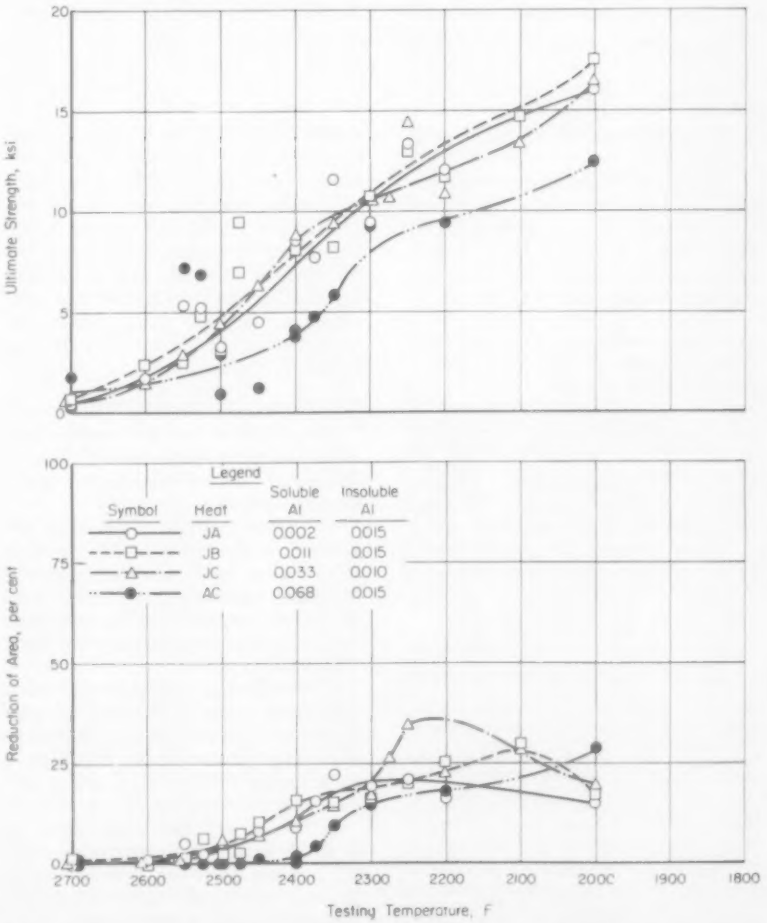

Fig. 8—The effects of aluminum on the high-temperature strength and ductility of steel of "T-1" composition

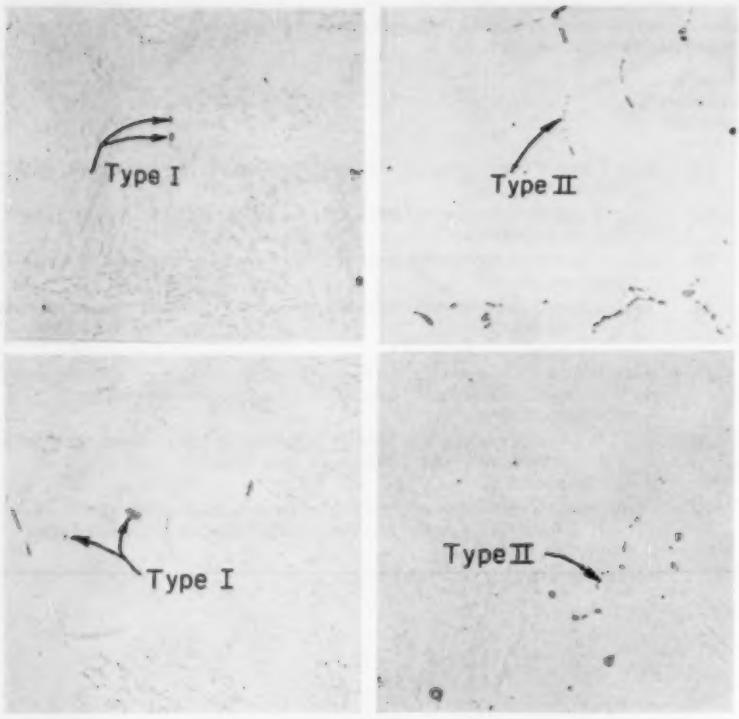

Fig. 9—Sulfide inclusions in experimental heats. Picral etch. × 500

above; the results are shown in Table 2.

Figure 9 shows photomicrographs taken of typical areas of specimens from Heats AA, AC, BA and BC. There was a trace of Type II sulfide inclusions in Heats AA and BA, but there appeared to be an insufficient quantity of sulfide present to form a continuous network around the grain. The significant difference between the specimens of Heats AC and BC was that the sulfides of Heat BC appeared to be more finely dispersed and, generally, smaller in size. The sulfide distribution in the other heats examined varied between the extremes shown in Fig. 9.

Table 3—Results of Restrained-weld Cracking Tests

Heat or specimen identification[a]		Number of cracked specimens per total of specimens tested	
Inserts	Welding filler wire	Visual inspection	Radiographic inspection
AA	AA	0/3	0/3
AB	AB	0/3	...
AC	AC	4/5	5/5
AC	BA	2/2	2/2
AC	BC	1/2	1/2
BA	BA	1/3	1/3
BC	BC	0/3	0/3

[a]AA = experimental heat of steel of "T-1" composition with low sulfur and phosphorous contents. AB = experimental heat of steel of "T-1" composition with medium sulfur and phosphorous contents. AC = experimental heat of steel of "T-1" composition with high sulfur and phosphorous contents. BA = experimental heat of steel of Type 1 weld-metal composition with low sulfur and phosphorous contents. BB = experimental heat of steel of Type 1 weld-metal composition with medium sulfur and phosphorous contents. BC = experimental heat of steel of Type 1 weld-metal composition with high sulfur and phosphorous contents.

Restrained-weld Cracking Tests

The results of the restrained-weld cracking tests are shown in Table 3. These results are summarized below:

1. Welds cracked that were deposited under high restraint with filler wire and inserts prepared from the experimental heat of steel of "T-1" composition having high sulfur and phosphorus contents (Heat AC).
2. Welds did not crack that were deposited under high restraint with filler wire and inserts prepared from the experimental heat of Type 1 weld metal having high sulfur and phosphorus contents (Heat BC).
3. Welds cracked that were deposited under high restraint with filler wires of Type 1 weld metals having low and high sulfur and phosphorus contents (Heats BA and BC) and with inserts machined from the experimental heat of steel of "T-1" composition having high sulfur and phosphorous contents (Heat AC).

When weld cracking occurred, the cracks were longitudinal, extending full length along the centerline of the weld; a few transverse weld-metal cracks were observed. Full-length cracks were observed in some instances immediately after welding. In these cases, the fractures apparently initiated and propagated at elevated temperatures as predominantly hot cracks. Other welds cracked on cooling to room temperature. In these cases, fracture probably initiated at elevated temperatures as a micro or macro hot crack and propagated at room temperature as a cold crack.

Examination of the fracture faces of the cracked welds showed that the longitudinal fractures were predominantly through weld metal. However, in most of the specimens examined, the vertical path of the fracture was in the heat-affected zone for distances along the length of the specimens varying from 1/8 to 1 in. Transverse sections were cut through these regions of heat-affected-zone failure and were examined metallographically. Figure 10 is a photomacrograph of a typical transverse section through a cracked, restrained-weld specimen. The notch effect at the root of the weld forced the crack to initiate at this root. The fracture appears to be predominantly transgranular in the heat-affected zone and in the

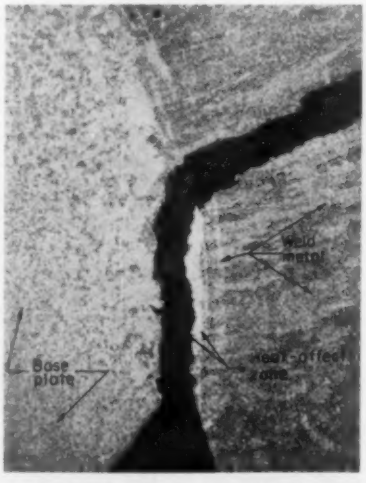

Fig. 10—Root of crack in restrained-weld-cracking specimen. Fracture may have initiated from a hot crack in the heat-affected zone and propagated at room temperature through weld metal. Inserts from Heat AC; filler wire from Heat BA. Nital etch. × 50. (Reduced about 40% on reproduction)

weld metal. Fracture may have occurred in two ways: (*a*) the fracture could have initiated as in the latter case mentioned above from a hot crack in the heat-affected zone and propagated at room temperature, or (*b*) the fracture could have initiated at the root of the weld when the joint was at, or near, room temperature.

No surface oxide was observed on the fracture face, but it is still possible that a small hot crack that was not open to the surface could have propagated at room temperature. It is not possible to establish conclusively how the fracture initiated and propagated. However, based on the results of the freezing-cycle hot-tension tests, the room-temperature propagation of an existing hot crack in the heat-affected zone appears to be a plausible explanation.

Discussion of Results

The results of the freezing-cycle hot-tension tests and restrained-weld cracking tests indicate that the experimental heat with 0.028 and 0.029 wt-% of sulfur and phosphorus, respectively, and a composition approximating that of "T-1" steel (Heat AC) is hot-crack sensitive.

The Type 1 weld-metal composition (Heat BC) with the same sulfur and phosphorous contents as the "T-1" steel composition (Heat AC) was not hot-crack sensitive. The significant observable difference in Heats BC and AC was in the size and distribution of the sulfide inclusions. Both heats contained predominantly Type II sulfide inclusions with small quantities of Type I inclusions. However, the Type II sulfide inclusions in Heat BC were finer and more scattered than in Heat AC. The reasons for the differences in size and distribution of the sulfide inclusions in the two heats are not known. Differences in chemical composition of the two heats probably account for much of the variations in hot-cracking sensitivity. For convenience, the compositions (weight percent) of the two heats (AC and BC) are listed below:

	AC	BC
C	0.17	0.13
Mn	0.89	1.07
Si	0.23	0.63
S	0.028	0.032
P	0.029	0.029
Ni	0.83	0.30
Cr	0.49	0.21
Mo	0.44	0.58
Cu	0.31	0.25
B	0.0024	0.0022
V	0.05	0.02
Al Sol	0.068	0.058
Al Inso	0.015	0.012
N_2	0.005	0.011

It is not possible to determine from these data which elements might have contributed to the change in hot-cracking sensitivity. Rollason, *et al.*,[5] found that silicon and nickel in excess of 0.1 and 0.5 wt-% respectively, promoted hot cracking. Wilkinson, *et al.*,[6] found similar results with 3Cr-Mo steels. Wilkinson proposed a formula based on chemical composition to predict the hot-cracking sensitivity of low-alloy steels as follows when all elements are expressed in weight percent:

$$HCS = \text{hot-cracking sensitivity} = \frac{C[S + p + (Si/25) + (Ni/100)] \times 10^3}{3Mn + Cr + Mo + V}$$

Based on the results of his tests, Wilkinson concludes that the *HCS*, or the cracking-sensitivity values, should be less than 4 for satisfactory weldability. This formula was applied to the experimental heats. The formula singled out the heat (AC) that was very hot-crack sensitive, but it failed to distinguish intermediate degrees of hot-crack sensitivity. This indicates that modification of the formula is necessary before it can be applied to steels of the general low-alloy quenched and tempered type. Other elements such as boron possibly should be included, or the relative weight of the existing elements in the formula should be modified.

One shortcoming of this formula is that the type of sulfide inclusion formed is not considered. It has been demonstrated by Sims, *et al.*,[7] that the type of sulfide inclusion formed is strongly dependent on the type and quantity of deoxidizer used in the production of the steel. For example, Sims' studies with medium carbon steel (0.32 C, 0.58 Mn, 0.29 Si, 0.035 S, 0.014 P) wt-% showed that Type I sulfide inclusions were formed up to a soluble aluminum content of 0.002 wt-%. With soluble aluminum contents of 0.002 to 0.015 wt-%, the undesirable Type II sulfide inclusions were formed. Soluble aluminum contents above 0.015 wt-% produced Type III sulfide inclusions. The aluminum contents at which the type of sulfide inclusions changed varied with the carbon content.

The heats (JA, JB and JC) that were prepared to study the effects of aluminum additions to high sulfur and phosphorus steels of "T-1" composition had very poor high-temperature ductility. There was little difference in the shapes of the hot-strength and hot-ductility curves of these heats as compared with Heat AC. Although there were some Type II inclusions in all three heats, the predominant type of sulfide inclusion in Heats JA, JB and JC changed from Type I to Type II with a change in soluble aluminum content of 0.002 to 0.011 wt-%. However, this change in predominant sulfide type did not affect the high-temperature mechanical properties of the steels.

Of the two mechanical properties measured in the freezing-cycle hot-tension test, the reduction of area appears to be more significant to the study of hot-cracking sensitivity. Strength at elevated temperature, nevertheless, is important. A specimen that develops strength before ductility usually will hot crack. However, a specimen that develops ductility before strength rarely cracks. The temperature interval from where strength and ductility begin to develop to the temperature where maximum ductility is attained is important. Generally, the steeper the reduction-of-area temperature curve, the less hot-crack sensitive the steel is. The curves for Heat CA in Fig. 7 illustrate behavior that is believed to be ideal for a material resistant to hot cracking. The maximum ductility attained is important. The significance of the temperature at which strength and ductility begin to develop is not known definitely. It would seem most desirable to begin to gain strength and ductility shortly after freezing is complete. A difference in hot-cracking susceptibility during welding between steels that begin to develop strength and ductility 100 and 300° F below the freezing point needs to be determined by some other technique, such as extensive restrained-weld cracking tests.

Summary and Recommendations

The significant findings of this investigation are briefly summarized as follows:

1. The hot-cracking sensitivity of submerged-arc welds with the Type 1 weld-metal composition is unaffected by sulfur and phosphorus contents up to at least 0.030 wt-% each. The Type 2 weld-metal composition is similarly unaffected by the same sulfur and phosphorous contents based on the

results of hot-tension tests only.

2. The specific effects of various elements on the hot-cracking sensitivity of the experimental steels studied were not determined. However, it is believed that the type, size and distribution of sulfide inclusions greatly influence hot-cracking sensitivity.

3. The data indicate that steel of "T-1" composition is hot-crack sensitive when the sulfur and phosphorus contents exceed about 0.020 wt-% each.

The significant differences in the hot-cracking sensitivities of the heats of steel of "T-1" composition and of Type 1 and Type 2 weld-metal compositions point to the necessity to determine the factors that affect weld- and base-metal hot-cracking sensitivity in constructional alloy steels. Research is needed to study the relationship between hot-cracking sensitivity and the following factors: chemical composition, deoxidation practice, inclusion type, size and distribution, microstructure and restraint.

Acknowledgment

The authors appreciate the many helpful comments and suggestions on this investigation by staff members at Battelle and United States Steel Corp. In particular, the suggestions of P. J. Rieppel and C. E. Sims were quite helpful.

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EUROPEAN WELDING RESEARCH

By Gerard E. Claussen

USSR

Svarachnoe Proizvodstvo for November 1960 contains the following:

• The oxidation of manganese in depositing a 1.5% Mn electrode on mild steel in CO_2 or under a slag is shown to occur most rapidly during transport of the drop, rather than in the weld puddle. Despite the short time of existence of the drop, its rate of reaction is higher because its surface area is large and it is farther from equilibrium than the puddle.

• The fatigue strength of butt joints with complete root fusion in a steel having 150,000 psi tensile strength was 48,000 psi. A deconcentrator, consisting of a notch $^1/_8$ in. wide, 0.02 in. deep, raised the fatigue strength to 20,000 psi.

• A photoelastic and fatigue study of welded gussets showed that a hollow gusset with rounded corners provided the best results.

The deposition of one or two longitudinal weld beads on the surface of 2-in. mild steel pipe, $^1/_8$- to $^5/_{32}$-in. wall caused high residual stresses which lowered the elastic limit in bending. The value of the pipe as a column therefore was reduced.

• Volume coefficient of expansion was found to be the factor governing ease of removal of slag from welds made with low-hydrogen electrodes. A coefficient of 3.46×10^{-5} was satisfactory, while 4.8×10^{-5} was unsatisfactory.

• As a result of wear tests on deposits on bucket teeth, a mixture called KBCh, applied by carbon arc was found better than 14 covered electrodes, four tube electrodes and three other pastes.

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Automatic Welding

Avtomaticheskaya Svarka for September 1960 contains the following articles:

• Measurements were made of the change in width of joint spacing during electroslag welding. For short joints in wide plates, the spacing tends to contract at first, then after a few feet of welding the spacing tends to open up. In circumferential joints the gap first opens the contracts. A mathematical analysis based on Timoshenko showed that buckling was proportional to the amount of heat due to welding per unit length of weld per unit thickness.

• Electromagnetic stirring of the slag and metal puddle in electroslag welding was found to improve the grain structure of the weld metal. Oscillograms showed a change in the current and an increase of up to 30% in melting rate was claimed.

• The electroslag principle was used to remove sulfur and sulfide inclusions from ball-bearing steel. An electrode of the steel was melted through a flux containing 55% Al_2O_3, 45% CaO to form an ingot $3^1/_4$ in. in diameter.

• Heterogeneity in the microstructure of welds is of two types: (1) nonuniform distribution of alloying elements and grain size, (2) lattice imperfections. The effect of 0.1% mischmetal in preventing grain boundary segregation of 0.010% sulfur in submerged-arc welds in nickel is demonstrated.

• An electron-microscope study of submerged-arc welds in mild steel made under high SiO_2-MnO flux revealed intergranular films that were absent in fluxes low in MnO and SiO_2. The films were believed to account for the low notch impact value of the weld metal. The melting point of nonmetallic inclusions associated with the films in a weld made with MnO-SiO_2 flux was 2000–2120° F, while the inclusions from a flux containing no MnO and only 27% SiO_2 melted at 2370° F, as determined in a microfurnace.

• Four surfacing electrodes for submerged-arc welding were found best to resist wear at 2100° F; molybdenum; a steel containing 1.7 C, 12.8 Cr, 13.3 W; a steel containing 1.6 C, 10.7 W, 15.6 Mo, 5.3 Co; and a steel containing 1.5 C, 14 Cr, 13 Mo and 4 Co.

(*Continued on page 422-s*)

Properties and Fabrication of High Strength 2¼% Chromium—1% Molybdenum Materials

Accurate control of heat treating procedures is a requisite to maintain the high strength levels of the quenched and tempered steel

BY R. C. GRIFFIN AND G. N. EMMANUEL

2¼% chromium—1% molybdenum material to ASTM Specifications A213 T-22, A387 Grade D and A335 P-22 in the annealed or normalized and tempered conditions has received widespread use in industry. However, this material, by accelerated cooling and controlled tempering, is capable of developing mechanical properties which are significantly higher than the minimum strengths required in the various ASTM Specifications.

This paper presents the data developed and fabrication practices to be observed when employing the 2¼% chromium—1% molybdenum material at a minimum tensile strength of 115,000 psi for the fabrication of heavy (up to 6 in. in thickness) walled pressure vessels for low temperature service where creep is not a design consideration. Figure 1 shows such a vessel.

The data show that 2¼% chromium—1% molybdenum material retains the required tensile strength levels at service temperatures up to 650° F with excellent ductility and notch toughness. The toughness properties have been determined by drop weight tests, and a correlation with Charpy V-notch test data has been attempted.

Since the high strength level of the material (for heavy sections) is developed by water quenching and tempering, the effects of extended exposure to elevated temperatures upon the mechanical properties were evaluated. For the maximum service temperatures under consideration, 650° F, aging tests at 800° F showed the mechanical properties of the material were unaffected. These samples were taken at varying thickness levels in 6 in. thick material.

While the 2¼% chromium—1% molybdenum material shows excellent mechanical properties in heavy sections, the fabrication of heavy walled pressure vessels by welding requires additional tests and evaluations. In common with any quenched and tempered ferritic material, the mechanical properties of the 2¼% chromium—1% molybdenum steel are a function of the tempering temperature, the properties decreasing with increasing tempering temperature. Since the welds in thick material of this type require a post-weld heat treatment, it was desirable to determine what effect various post-weld heat treatment temperatures had on the mechanical properties.

The results of tests at temperatures of 1025 and 1125° F show that the material retains the required minimum tensile strength for a period of 60 hr at 1025° F, the limit of testing time. When heat treated at 1125° F, however, the properties are below 115,000 psi minimum tensile strength when held at such temperatures in excess of 25 hr. These data were fully considered in the fabrication of pressure vessels from high strength 2¼% chromium—1% molybdenum materials.

In the welding operations, both manual metal arc and automatic submerged-arc welding techniques were developed and employed in pressure vessel fabrication. This paper relates the data developed. It is in this particular area—the development of weld metals and welding procedures—that additional work is warranted for improved notch tough weld metals for low temperature service.

While the developed data show that the material is excellent for heavy walled pressure vessel applications, the actual fabrication of such vessels requires close fabrication process controls. The basic process controls which the authors' company employed in the fabrication of two heavy walled pressure vessels produced from high strength 2¼% chromium—1% molybdenum materials are outlined. These controls were developed to protect the high strength levels of the base materials during fabrication.

The high strength levels developed by 2¼% Cr—1% Mo material in the quenched and tempered condition permit the fabrication of extremely high pressure vessels with thinner walls when advantage is taken of these strengths for higher allowable stresses.

Material

Seven commercial heats of the 2¼% Cr—1% Mo material were studied in this investigation. No attempt was made to restrict the chemical composition in any fashion, and the analyses were shown in Table I.

Material from heat number A-2811 was rolled into 12 and 6 in. thick plate. The material from heats B-1161, B-1177 and A-3794 was made into hollow forgings which had wall thicknesses of 7 in., while the material from the last three heats shown in Table I was rolled into 2 in. plate.

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Paper to be presented at the AWS National Fall Meeting to be held in Dallas, Texas, during Sept. 25-28, 1961.

Heat Treatment

It was found at the outset of this investigation that a normalizing treatment followed by tempering was not suitable to obtain the desired mechanical properties in heavy sections of the 2¼% Cr—1% Mo material. As a result, all of the subsequent properties presented in this paper are the results of water quenching from a temperature of 1750–1775° F, and tempering at 1100-1150° F. The quenching operation was either a dip quench or a spray quench.

In some cases, additional heat treatments have been imposed to simulate fabrication procedures, and this is noted where applicable.

Results of Material Studies

Room Temperature Mechanical Properties

The mechanical properties of the seven heats of 2¼% Cr—1% Mo material were investigated with results as noted in Table 2. It will be noted that the 12 in. plate did not develop the required mechanical properties at the ¼ T and center locations; therefore, no further data from this plate are reported. However, the properties of the 2¼% Cr—1% Mo material up to 7 in. thick exhibits the desired properties throughout the thickness.

Impact and Drop Weight Test Results

When using quenched and tempered material at relatively high strength levels, a knowledge of the resistance to crack propagation is always desirable. This quality is usually measured by one of two methods; Charpy V-notch tests and drop weight tests—Tables 3 and 4. Both these methods, although not carried out on each heat of material, were used to determine the toughness of the 2¼% Cr—1% Mo material, and a correlation between the two was attempted.

The concept of nil ductility temperature as the temperature at which failure will propagate catastrophically has been generally accepted. Pellini and Puzak* originally used the explosion bulge test to determine NDT and then correlated their findings with the so-called drop weight test which is a simpler test. However, even the drop weight test requires equipment not in general use; therefore, a correlation between NDT and the conventional Charpy V-notch test is desirable.

The drop weight results in Table 4 show reasonably good agreement for heats A-3874 and A-3875, even though there are some unexplained inconsistencies in the data. However, a value of −30° F for the nil ductility temperature appears to be warranted for these two heats.

In order to establish a correlation between the drop weight test and the more conventional Charpy V-notch test, Charpy transition curves are drawn—Figs. 2 and 3. By determining the ft-lb of energy which correspond to the NDT, a "fix" between Charpy V-notch values and nil ductility temperature is obtained. For example, Figs.

Table 1—Chemical Analysis (%) of Materials Investigated

Heat no.	C	Mn	Si	Cr	Mo	P	S	Ni	Cu
A-2811	0.11	0.46	0.31	2.13	1.00	0.017	0.016	0.11	0.09
B-1161	0.12	0.47	0.45	2.43	1.02	0.029	0.022	0.18	...
B-1177	0.12	0.48	0.38	2.41	1.02	0.024	0.015	0.16	...
A-3794	0.13	0.47	0.25	2.58	1.10	0.028	0.022	0.15	...
A-3874	0.10	0.46	0.41	2.12	0.98	0.017	0.013	0.14	0.08
A-3875	0.09	0.46	0.37	2.37	1.02	0.015	0.016	0.13	0.07
A-3876	0.11	0.46	0.32	2.17	1.02	0.018	0.020	0.08	0.07

Table 2—Mechanical Properties of Material Investigated

Heat no.	Thickness, in.	Location	Tensile strength, psi	Yield strength, psi, 0.2% offset	Elongation, % in 2 in.	Reduction of area, %
A-2811	12	Surface	128,000	114,000	20.0	67.6
		¼ T	100,000	63,000	21.5	57.3
		Center	101,500	75,000	21.5	47.2
A-2811	6	Surface	134,000	123,000	19.5	62.9
		¼ T	129,250	115,500	21.0	63.5
		Center	120,750	106,000	20.0	63.4
B-1161	7	¼ T	142,500	121,000	19.0	64.4
B-1177		¼ T	127,000	113,500	20.0	67.5
A-3794		¼ T	124,500	111,000	22.5	71.5
A-3874	2	¼ T	132,600	119,300	18.0	70.0
A-3875		¼ T	138,500	123,600	19.5	69.8
A-3876		¼ T	131,700	115,800	20.5	67.2

Table 3—Charpy V-notch Impact Test Results (Ft-Lbs, All Tests From ¼ T Locations)

Heat No.	Thickness, in.	Room temperature	+10° F	−20° F	−50° F	−75° F	−80° F	−100° F	−110° F
A-2811	6	90, 85, 81, 80, 72	72, 71, 66, 55, 39, 31	...	82, 58, 50, 50, 40, 35	46, 46, 43, 31, 29, 13, 9	33, 28, 14	...	...
A-3874	2	72	...	41, 43	70, 41, 40	26, 38, 40	32, 34, 36	17, 20	...
A-3875	2	52	...	40, 47	36, 36, 26	30, 30, 26	20, 21, 16	12, 17	...
A-3876	2	...	60, 59, 54	56, 45, 42	41, 30, 29	...	...	...	28, 23, 17, 15

* Puzak, P. P., and Pellini, W. S., "Evaluation of the Significance of Charpy Tests for Quenched and Tempered Steel," The Welding Journal, (6), Research Suppl., 275-s to 290-s (1956).

Table 4—Drop Weight Test Results of High Strength 2¼% Cr—1% Mo Steel

Heat No.	Temperature, ° F	Fracture, Remarks
A-3874	−50	F—F
	−40	NF—NF—F—F
	−30	NF—NF—NF—NF—NF—F
	−20	NF—NF
	−10	NF—F
A-3875	−50	F—F
	−40	F
	−30	NF—NF—F
	−20	NF—NF—F
	−10	NF—NF

NF = no failure. F = failure.

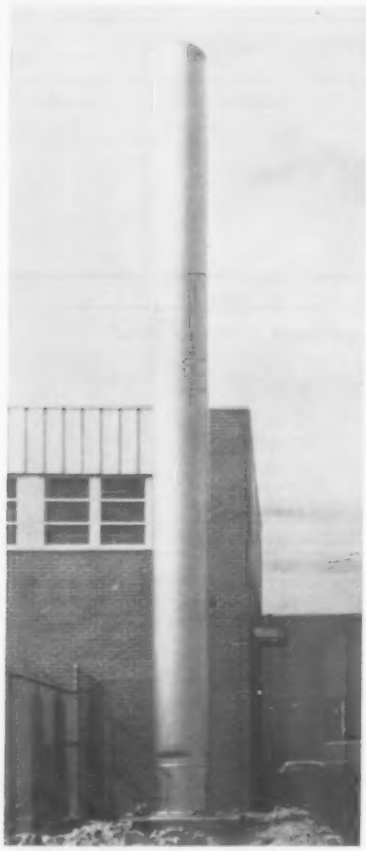

Fig. 1—Pressure vessel fabricated from high-strength 2¼% Cr – 1% Mo steel

Table 5—Short Time High Temperature Tensile Tests

Heat No.	Test temperature, °F	Tensile strength, psi	Yield strength, psi	Elongation, % in 2 in.	Reduction of Area, %
B-1161	Room	145,700	128,600	20.5	62.5
	200	139,500	124,800	19.5	61.4
	300	136,300	117,900	18.0	57.7
	400	134,800	113,600	18.0	57.7
	650	132,500	...	19.0	64.4
A-3874	Room	132,600	119,300	18.0	70.0
	200	130,500	119,500	15.5	68.6
	400	124,200	111,900	16.5	67.2
	600	121,800	109,900	13.5	62.9
	700	118,300	106,800	15.0	67.7
A-3875	Room	138,500	123,600	19.5	69.8
	200	128,800	115,600	17.0	68.4
	400	122,600	110,600	17.5	68.6
	600	119,100	106,900	13.0	67.4
	700	115,900	103,900	14.0	68.4
A-3876	Room	131,700	115,800	20.5	67.2
	200	125,700	112,400	17.0	67.8
	400	117,700	104,000	17.0	67.2
	700	113,600	100,600	17.0	65.1

2 and 3 show that Charpy V values of 37 and 32 ft-lb respectively for heats A-3874 and A-3875 correspond to the NDT temperatures.

Assuming that these heats are representative of high strength 2¼% Cr—1% Mo material, the temperature at which a Charpy V value of 35 ft-lb is obtained will correspond to NDT. Therefore, depending upon the design of the vessel and its operating conditions, a temperature at which the material must meet 35 ft-lb will be chosen. In cases where the vessel is to operate under completely elastic conditions, and will not be subject to gross deformations, a Charpy V value of 35 ft-lb at the minimum operating temperature should be considered. For more severe service, where appreciable localized plastic deformation may be expected, a temperature of 30–50° F below the minimum operating temperature should be the temperature at which acceptance impact tests are conducted.

Effect of Simulated Service Conditions

Since vessels fabricated from 2¼% Cr—1% Mo material may operate at temperatures as high as 650° F, short time high temperature properties were determined. The results are shown in Table 5.

In order to ascertain, the retention of impact properties after periods of exposure to service temperatures, 6 in. plate samples were aged for 1000 hr at 800° F—Table 6.

Welding Materials

Weld Metal Development

Welding development was carried

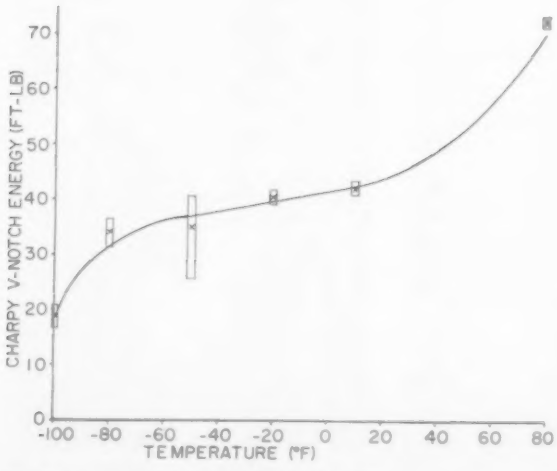

Fig. 2—Impact transition curve (Heat A3875)

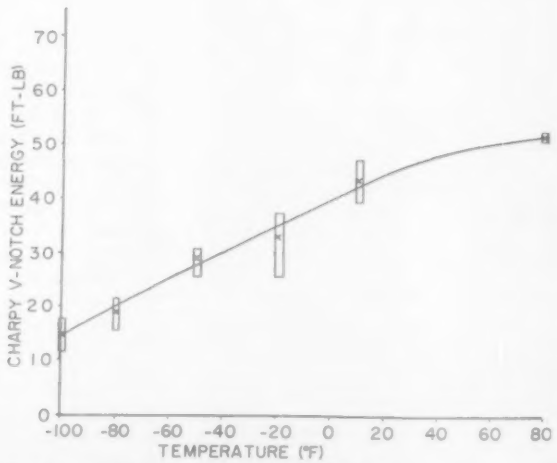

Fig. 3—Impact transition curve (Heat 3874)

Table 6—Effect of 1000 Hr Aging at 800° F on Impact Properties of Heat No. A-2811 Samples from 1/4 T Location (Charpy V-notch, ft-lb)

Room Temperature, ° F	+10° F	−50° F	−75° F
58	46	70	17
69	55	64	5
72	53.5	43	59
85+	85	...	7

Table 7—Chemical Composition Range (%) of H-120 Electrode

C	Mn	Si
0.03–0.06	0.68–0.92	0.15–0.21
Cr	Ni	Mo
1.25–1.91	2.04–3.13	0.82–1.00

Table 8—Room Temperature Mechanical Properties of H-120

	Tensile strength, psi	Yield strength, psi	Elongation, %	Reduction of area, %
As-welded	131,500	122,800	17.5	54.4
S.R. 1 hr at 1150° F	122,000	113,600	13.5	57.9
S.R. 2 hr at 1150° F	107,000	97,500	20.0	62.0
S.R. 4 hr at 1150° F	107,500	98,500	20.0	62.0
S.R. 10 hr at 1150° F	98,000	89,000	22.5	63.5

Table 9—Effect of Temperature on Impact Properties of H-120 Weld Metal

	+80° F	+32° F	0° F	−50° F	−100° F
As-welded	...	26, 29, 31	25, 26, 30	25, 25	11, 15, 16
S.R. 1 hr at 1150° F	40, 46, 51	39, 40, 45	31, 35, 36	16, 24, 29	10, 11, 15
S.R. 2 hr at 1150° F	...	...	47, 56, 68	...	11, 18, 23
S.R. 4 hr at 1150° F	...	...	45, 46, 53	...	10, 16, 22
S.R. 10 hr at 1150° F	...	...	72, 78, 85	...	12, 26, 38

out with respect to both the manual metal arc and automatic submerged arc methods of welding. The purpose of these investigations was to formulate weld metals and procedures which would result in weldments with mechanical properties comparable to the high strength base material.

Manual Electrode Development

Under a Bureau of Ships Contract, NObs-72187, the authors' company developed an electrode capable of meeting a minimum tensile strength of 120,000 psi and a Charpy V-notch of 20 ft-lb at −70° F after a post weld stress relieving heat treatment. This electrode, designated as H-120, has a mineral, low hydrogen, lime type coatings and the nominal composition range indicated in Table 7.

Mechanical Properties

All weld metal tension specimens cut from restrained joints made in 1 in. plate with H-120 electrode gave the results in Table 8.

As noted, there is a gradual decrease in the strength properties with increasing time at 1150° F.

Impact Properties

Charpy V-notch impact strengths were determined for as-welded and stress relieved H-120 weld metal between −100 and +80° F. The results are shown in Table 9.

Submerged-arc Welding Development

This phase of the investigation indicated that three types of submerged arc weld deposits would provide a satisfactory weld metal. These are (*a*) 5% Cr—1% Mo, (*b*) 2.5% Ni—1% Cr-Mo-Cu and (*c*) 1.5% Ni—1% Cr-Mo-Cu (AT-17).

Table 10—Properties of Submerged-arc Butt Weld in 6-in. Thick 2 1/4% Cr—1% Mo Plate (5% Cr—1% Mo Weld Metal) Steel

Weld metal chemical analysis, %

C	Mn	Si	Cr	Ni	Mo
0.046	0.65	0.44	5.02	0.10	1.00

All weld metal tension tests

Tensile strength, psi	Yield strength, psi	Elongation, %	Reduction of area, %
121,000	111,000	16.0	53.7

Transverse tension tests

Tensile strength, psi	Fracture location
111,000	Weld
116,000	Weld

All weld metal Charpy V-notch results, ft-lb

Room temp., ° F	+10° F	−20° F	−50° F	−75° F
30	22	30	16	9
35	20	22	17	75
35	30	20	27	18

Table 11—Properties of Submerged-arc Butt Weld in 6-in. Thick 2 1/4% Cr—1% Mo Steel Plate (2.5% Ni—1% Cr-Mo-Cu Weld Metal)

Weld metal chemical analysis, %

C	Mn	Si	Cr	Ni	Mo	Cu
0.05	0.85	0.21	1.06	2.50	0.88	0.47

All weld tension tests, heat treatment—S.R. 1100° F—6 hr plus S.R. at 1025° F

Time at 1025° F, hr	Tensile strength, psi	Yield strength, psi	Elongation, %	Reduction of area, %
0	119,000	107,000	16.5	49.0
12	117,500	103,750	21.0	51.5
36	116,500	106,500	20.5	57.1
42	118,000	108,750	21.5	53.8

Transverse tension test results, heat treatment—S.R. 1100° F—6 hr

Tensile strength, psi	Fracture location
125,200	Weld
120,600	Weld
130,000	Weld
128,000	Weld

Side bend—4 satisfactory

Charpy V-notch impact results, ft-lb

Test temp., ° F	S.R. at 1100° F for 6 hr
Room	27, 30, 30, 33
+10	20, 21, 22, 23
−50	17, 20, 21, 22
−100	17, 18, 18.5, 20

5% Cr—1% Mo. In the welding development of the 5% Cr—1% Mo weld metal, a butt weld was made in 6 in. thick high strength 2 1/4% Cr—1% Mo plate. The submerged-arc welding was performed with a 5% Cr—1/2% Mo wire with a neutral flux modified with the addition of 1/2% molybdenum. The chemical analysis and mechanical properties obtained from this weldment are listed in Table 10.

Side bend tests on the 5% Cr—1% Mo welds were satisfactory.

2.5% Ni—1% Cr-Mo-Cu. In the development of the 2.5% Ni—1% Cr-Mo-Cu submerged-arc weld metal deposit, a 6 in. thick high strength 2 1/4% Cr—1% Mo butt weld test plate was produced. The welding was performed using a manganese-molybdenum filler wire with a bonded type flux. The chemical analysis and mechanical properties obtained are listed in Table 11.

1.5% Ni—1% Cr-Mo-Cu (AT-17). In the development of the 1.5% Ni—1% Cr-Mo-Cu weld metal analysis, a 2 in. thick butt weld test plate of high strength

Table 12—Properties of Submerged-arc Butt Weld in 2 in. Thick 2¼% Cr—1% Mo Steel Plate (1.5% N.—1% Cr Mo-Cu Weld Metal)

Chemical analysis, %

C	Mn	Si	Cr	Ni	Mo	Cu
0.10	1.16	0.51	1.10	1.43	0.45	0.20

All weld tension tests, heat treatment—1075–1125° F—2-hr

Tensile strength, psi	Yield strength, psi	Elongation, %	Reduction of area, %
126,000	110,000	20.0	54.3

Transverse tension tests

Tensile strength, psi	Fracture location
125,800	Plate

Charpy V-notch impact tests, heat treatment—1075–1125° F—2-hr

Test temperature	Ft-lb
−50° F	21, 23, 25

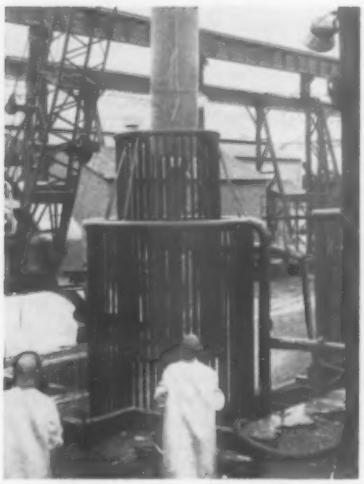

Fig. 4.—Spray quench unit for quenching shell sections

Fig. 5—Water spray quenching of shell section

2¼% Cr—1% Mo material was employed. The filler wire was a braided wire with control of the weld metal analysis obtained by the analyses of the wires. A neutral flux was employed. During the welding of the test plate with the braided wire electrode, no cutting of the contact shoe was observed and the welding arc was exceedingly quiet and stable. The results of the chemical analysis and mechanical properties are listed in Table 12.

Side bend tests on the weldment were satisfactory.

Pressure Vessel Fabrication

In the fabrication of pressure vessels from 2¼% Cr—1% Mo material, which are heat treated by liquid quenching and tempering to high strength levels, the procedure employed gave assurance that strength levels of 115,000 psi tensile strength and 100,000 psi yield strength were retained upon completion of fabrication. To date, the authors' company has fabricated two vessels from high strength 2¼% Cr—1% Mo. One vessel was 34 in. OD × 6 in. min wall, at a design working pressure of 15,000 psi and a design basis of 3:1 safety factor. The second vessel was 20 in. ID with 4⁹/₁₆ in. min wall at a design working pressure of 10,000 psi and a 4:1 safety factor.

As has been shown in previous sections of this paper, the materials were melted to the standard chemistry range of ASTM Specifications. The shell sections of the pressure vessels were then formed by forging as seamless forgings. The forging operations consisted of piercing and drawing an ingot which resulted in 7 in. wall seamless cylinder. The shell sections were made heavy for machining tolerances after heat treatment and to secure the required concentricity of the finished vessel. These sections were then water quenched in a spray type fixture from a temperature of 1750–1800° F. This spray quenching fixture consisted of tubes in the vertical position between two headers for water supply, as illustrated in Figs. 4 and 5. The tubes were perforated with ⅛ in. diam holes in uniform set patterns to obtain uniformity of quenching. The fixture was designed to permit simultaneous spray quenching of both the inner and outer surfaces. Spray quenching in preference to dip quenching was selected because it had been demonstrated that this procedure provided more uniform properties as measured by impact results. This is especially true in thick vessels.

Control of the temperatures from which the shells were quenched was accomplished by the use of attached thermocouples. The heads for the pressure vessels were also fabricated from material of the same analysis as the shell sections. These heads were liquid spray-quenched by means of special "toadstool" type spray quenching fixture shown in Figs. 6 and 7. These special fixtures permitted simultaneous spray quenching of both the outside and inside surfaces of the finished head. The heat treating temperature and method of temperature control for the heads duplicated that employed for the shell sections. The shell sections

Fig. 6—Spray quench unit for quenching vessel heads

Fig. 7—Water spray quenching of vessel head

Table 13—All Tests Water Spray Quenched from 1750–1800° F

Stress relieving temperature, ° F	Hours at temperature	Tensile strength, psi	Yield strength, psi	Elongation in 2 in., %	Reduction of area, %
None	..	165,000	152,150	17.5	57.8
None	..	166,000	156,850	14.0	51.6
1100	6	149,000	134,500	18.0	59.7
1100	6	142,500	121,000	19.0	64.4
1100	12	126,500	114,000	21.5	70.1
1100	18	122,000	108,500	19.5	59.4
1100	24	119,250	104,500	23.5	68.4
1100	30	117,200	101,500	22.0	68.8
1125	15	120,500	106,500	21.0	67.5
1125	27	114,500	102,700	23.5	70.7
1125	39	113,750	100,000	23.5	70.8
1025[a]	12	140,000	127,500	21.0	65.6
1025[a]	24	139,500	123,500	18.5	62.1
1025[a]	48	137,500	126,500	20.0	62.7
1025[a]	60	137,500	125,000	20.0	62.5

[a] Samples were given an initial 1100–1125° F heat treatment prior to the 1025° F heat treatments.

and heads were given a tempering treatment subsequent to the spray quenching at a temperature of 1100–1125°F, being held at temperature for 1 hr per in. of thickness. Upon completion of this heat treating sequence, test specimens were removed from the materials to verify that the desired mechanical properties were met. The shell sections and head were then machined to final dimensions of the vessel.

To evaluate the effect of the tempering and the post weld heat treatments required during fabrication upon the base material mechanical properties, a series of tensile tests was performed with material tempered at temperatures of 1025, 1100 and 1125° F, for various times at these temperatures. The results of these tests are shown in Table 13.

These data showed that 60 hr at 1025° F had no significant effect upon the mechanical properties of the material. It should be noted that the material was given an initial 1100–1125° F tempering heat treatment prior to the additional 1025° F heat treatment. The minimum required mechanical properties were still maintained after 30 and 25 hr at stress relieving temperatures of 1100 and 1125° F respectively.

In addition to evaluating the base material, the nickel alloy weld metal was also evaluated as shown in Table 14. These data also revealed no significant effect upon the mechanical properties of the weld metal after 42 hr at a temperature of 1025° F.

The purpose of this evaluation was to determine the post-weld heat treatment cycles to be employed in fabrication which would result in vessels which had the desired mechanical properties upon completion of all heat treating operations.

As a result of this investigation, the heat treating cycles for complete fabrication of the vessel were selected to reduce high peak stresses resulting from welding by intermediate thermal heat treatments and a final stress relieving heat treatment to place the vessel in the desired condition. The heat treatment cycle consisted of:

1. Liquid quenching the base materials from a temperature of 1750–1800°F.
2. An initial tempering heat treatment at 1100–1125° F of the base materials prior to welding.
3. Intermediate post weld heat treatments of 1025° F for the reduction of high welding stresses.
4. A final post weld heat treatment of the vessel at a temperature of 1100–1125° F.

Table 14—2.5% Ni—1% Cr-Mo-Cu Alloy Weld Metal Tempered at 1100° F for 6 hr plus Tempering at 1025° F

Temper time at 1025° F hr	Tensile strength, psi	Yield strength, psi	Elongation in 2 in., %	Reduction of area, %
0	119,000	107,000	16.5	49.0
12	117,500	103,750	21.0	51.5
36	116,500	106,500	20.5	57.1
42	118,000	108,750	21.5	53.8

Fig. 8—Circumferential shell seam with manual metal arc H-120 electrode deposit prepared for automatic submerged arc welding

The shell of the pressure vessel was fabricated by joining the sections together with butt welds employing 2¼% Cr—1% Mo chill rings which were subsequently removed. A preheat of 300° F minimum was applied for each weld. The first one-half inch of weld metal thickness was deposited by the manual metal arc process employing H-120 coated electrodes. Figure 8 shows the weld groove with manual metal arc welding completed and prepared for submerged-arc welding. The balance of the weld was then completed by the submerged arc method of welding which resulted in the 2.5% Ni—1% Cr-Mo-Cu weld metal deposit previously discussed in this paper. Upon completion of each of these circumferential butt welds, the vessel was post-weld heat treated at 1025° F for 6 hr to reduce high residual stresses in the vessel weldment. The first head was assembled to the shell employing identical welding and post weld heat treatment procedure. The internal and external weld surfaces were examined by the liquid penetrant method of inspection. Following this inspection, the weld seams were subjected to radiographic examination. All defects were removed by chipping and grinding, and these areas repaired by manual metal arc welding with H-120 electrodes with a 300° F minimum preheat and a 1025° F post-weld heat treatment. Such repaired areas were again nondestructively examined. All repairs were completed and examined prior to final cleaning operations.

The vessels were then given their final inside surface cleaning by a combination of grinding and blasting operations prior to attachment of the final closure head. An inert atmosphere of nitrogen was maintained in the vessel to reduce atmospheric oxidation of the base materials to a practical minimum level. The final closure head was also cleaned by these methods; however, this final cleaning was accomplished immediately prior to its assembly to the shell since neither vessel had an access opening which would permit a detailed cleaning operation subsequent to assembly of the final closure joint.

The final closure joint of the vessels was accomplished by completing the first pass by manual gas tungsten-arc welding. Of necessity, the groove employed was designed to accommodate a preplaced 2¼% Cr—1% Mo 3/32 in. diam wire to the nose of the prepared welding groove. The head was assembled to the mating weld groove surface of the shell. The method of attaching filler wire at this point of fabrication is critical to ensure that the filler wire will remain in place upon the application of welding preheat and to ensure the actual fusing of this filler metal wire to the noses of the weld groove. The wire was tacked in place a minimum of every 1 in. along the length of the wire. A very large number of tacks was required to prevent fall-away during welding.

Upon fitting the head in place and properly tacking the filler wire, a purge of the vessel was initiated with argon gas. This purge was maintained until an oxygen meter reading of less than 5% oxygen was obtained. The purging was accomplished by introducing the gas through the head already attached to the vessel and using the final closure head nozzle exhaust. A minimum preheat of 300° F was then applied and the first pass consisting of fusing the preplaced 3/32 in. diam wire was accomplished by manual gas tungsten-arc welding. Upon completion of this pass, the next 1/2 in. of weld metal was deposited by the manual metal arc process employing H-120 covered electrodes. The balance of the weld was completed by the automatic submerged-arc process as employed on the previous circumferential seams. The vessels were then given a postweld heat treatment at 1025° F. The outside surface of the final closure weld was liquid-penetrant inspected and the seam radiographically examined. All defects were removed, repaired, post-weld heat treated at 1025° F and reinspected.

Upon completion of all welding and nondestructive testing, each vessel was given a final post weld stress relief heat treatment at 1100–1125° F. To assure that no damage to the circumferential weld seams had resulted from the post weld heat treatment, all seams were again radiographically inspected; in all cases satisfactory results were obtained. The finished vessels were then subjected to hydrostatic test pressures of 25,000 psi for vessel designed at 15,000 psi working pressure and 15,000 psi for the 10,000 psi vessel. Girth dimensions were taken both before and after these hydrostatic tests to assure that the vessels did not plastically deform during testing.

Conclusions

1. 2¼% Cr—1% Mo steel at high strength levels has been demonstrated to be suitable for the fabrication of pressure vessels. The fabrication of these vessels requires accurate control of heat treating procedures to maintain the high strength levels of the quenched and tempered steel.

2. Minimum mechanical properties of 115,000 psi tensile strength and 100,000 psi yield point and adequate resistance to impact loading temperatures of −30° F are obtainable in finished vessels of this quenched and tempered material.

3. Manual and submerged-arc weld metals have been developed with room temperature mechanical properties which are comparable to the quenched and tempered 2¼% Cr—1% Mo steel. Additional investigation of the mechanical properties of the weld metals after simulated service condition treatments at temperatures up to and including 650° F is being conducted.

4. This paper has shown the possibility of drastically reducing the thickness of pressure vessel walls by taking advantage of the increased strength of alloy steels which can be realized by proper heat treating and fabrication procedures. Neither of the vessels described could have been economically built except for the application of liquid quenched and tempered material.

Acknowledgment

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Accelerated Cooling of Carbon Steels for Pressure Vessels

Spray quenching is found to raise tensile strength and improve the notch ductility of ABS-B and ABS-C steels

BY D. A. CANONICO, E. H. KOTTCAMP AND R. D. STOUT

FOREWORD. The Fabrication Division of the Pressure Vessel Research Committee of the Welding Research Council is sponsoring a research program at Lehigh University to determine the effect of accelerated cooling on the mechanical properties of plain carbon and low-alloy steels. The authors are grateful for the support of PVRC and for the help and advice of the division members.

Introduction

As design requirements for pressure vessels have become more stringent, the need for heavier sections of carbon steels has encouraged consideration of steels of higher strength. It was realized that higher strength levels must be obtained without loss of notch ductility. Two avenues exist for improving the mechanical properties: an increase in the alloy content and/or the application of appropriate heat-treating techniques.

Increasing the carbon content to gain tensile strength results in a lowering of notch ductility and weldability. Although increased alloy additions may be used to raise both strength and toughness, they usually detract from weldability. In addition they add to the cost of the steel and its fabrication. Thus the alternative of heat treating carbon steels to enhance tensile strength is attractive.

In sections over 1 or 2 in. thick, normalizing heat treatment is helpful and generally mandatory to produce suitable properties. Because accelerated cooling is only slightly more expensive than normalizing, it has become increasingly attractive to utilize spray quenching as a means of enhancing pressure vessel steel properties.

Previous investigations at Lehigh University have shown the extent of the improvement in the properties of pressure vessel steels possible from accelerated cooling. These tests[1, 2] were conducted on a series of low-alloy steels under consideration for use in pressure vessels. The procedure in these studies was to simulate the cooling rates encountered at the center and quarter-points of a range of thicknesses of spray quenched and normalized steel plates. The improvement of mechanical properties observed in heavy-section plates by means of accelerated cooling suggested the possibility of usefully improving the mechanical properties of low hardenability steels in thinner sections.

These steels do not undergo martensitic hardening and must be improved through a more favorable distribution of the carbide and ferrite microconstituents. Because of the limited thermal conductivity of steel, the variation of the cooling rate from surface to center can be expected to produce a more favorable carbide-ferrite aggregate at the surface than at the center. This difference in microstructure should be reflected in the mechanical properties at various locations across a steel plate. In that portion of the investigation reported here, the extent of variation encountered in $^1/_2$-and 1-in. thick plates was examined. It was felt desirable to describe the response of the steels to accelerated cooling in terms of specific cooling rates. Because the published data on spray-quenching are scant, extensive and careful measurements of cooling rates were obtained on plates up to $4^1/_2$-in. thick.

In this paper are reported data obtained from the cooling rate study as well as the mechanical properties obtained by spray quenching plain carbon steels. Several low-alloy steels are currently being investigated and will be reported at a later date.

Cooling Rate Studies

Only limited data are available in the literature relative to the cooling rates obtained by quenching heavy plate sections. This is particularly true for modern spray-quenching techniques using large volumes of high-pressure water for treating large, thick alloy-steel plates. It was decided to establish the representative cooling rates that can be expected in plates ranging from $^1/_2$ to 10 in. thick when quenched in a high-efficiency spray fixture.

The cooling rates are reported as the average rate between the austenitizing temperature and a temperature midway between the austenitizing temperature and quenchant temperatures. This criterion was selected, because it minimizes the irregularities in the cooling introduced by the steel recalescence during transformation. The rate at 1300° F, which has been frequently reported, may be rendered meaningless in low-carbon steels by the formation of proeutectoid ferrite. Similar disturbances occur at lower temperatures because of pearlite or bainite formation, the temperatures varying with the cooling rate and the steel composition.

Equipment

A survey was conducted to establish the water spray rates employed in commercial installations. It was learned that 0.3 cu in. of water per sq in. of surface per side per sec is considered satisfactory and practicable. A spray apparatus capable of delivering the desired quantity and distribution of water was designed and is shown in Fig. 1.

Experimental Procedure

The section sizes subjected to accelerated cooling were $^1/_2$, 1, $1^1/_2$, 2, 3 and $4^1/_2$ in. thicknesses. The plate size was 12 by 12 in., which was considered adequate to

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Fig. 1—Apparatus for spray-quenching 12- by 12-in. plates at commercial flow rates

eliminate the edge effects in the $4^1/_2$-in. thick plate. Cooling rates were measured at the mid- and quarter-thickness positions. Porcelain-insulated chromel-alumel thermocouples were percussion welded to the plate at the bottom of 6-in. deep holes located 6 in. from either side. The thermocouples were protected from the water by stainless steel tubes that extended above the top of the container (Fig. 1) when the plate was in the spraying position.

The water flow rate was measured for each plate quenched. The average flow rate delivered by this apparatus was 0.28 cu in./sq in./side/sec.

The plates that were to be air-cooled were wire brushed to remove any loose scale. Those plates being spray quenched did not require the wire brush treatment because of the thermal shock of the water. When the temperature of the plate reached 1600° F, the automatic temperature recording devices were activated. In the case of spray quenching the water and temperature devices were activated simultaneously.

Table 1—Experimental Cooling Rates for Normalized and Spray Quenched Plates of Various Thicknesses

Cooling method	Plate position	Cooling rate in ° F per sec to half-temperature[a]					
		$^1/_2$ in.	1 in.	$1^1/_2$ in.	2 in.	3 in.	$4^1/_2$ in.
Spray quenched	Quarter-thickness	36	18	13	11	6.2	3.7
	Mid-thickness	31	18	12	7	5.7	3.1
Normalized	Quarter-thickness	1.5	.084	.064	.054	0.32	0.26
	Mid-thickness	1.5	.084	0.60	0.48	0.32	0.26

[a]The cooling rate to half-temperature is determined by dividing the first half of the temperature change during cooling by the time required to produce the first half change. Example: Quench from 1600° F with water at 60° F. The half-temperature is (1600 — 60/2) + 60 = 830° F. If the time to cool from 1600 to 830° F were 20 sec, then the cooling rate to half-temperature would be 770° F/20 sec = 38.5° F/sec.

Results

A sample calculation of a half-temperature cooling rate is given at the bottom of Table 1. This wide temperature range, 1600 to 830° F, encompasses nearly all of the metallurgical changes in the carbon steels that can affect the cooling rate by recalescence.

The experimental cooling rates obtained for the various section sizes are given in Table 1. Each rate represents the results of at least two determinations. The results are plotted in Fig. 2. The mid-thickness and quarter-thickness cooling rates for the air-cooled specimens were essentially identical. Spray quenching resulted in a slight but significant difference between the mid-thickness and quarter-thickness locations.

Discussion of Cooling Rate Study Results

The data in Table 1 and Fig. 2 were used as the basis for deriving mathematical equations that would permit the extrapolation of these cooling rates for section sizes from $4^1/_2$ up to 10 in. The general equations that were derived are as follows where (C.R.) is cooling rate (in ° F/sec) and t is plate thickness (in inches):

1. For air-cooling.
   mid-thickness *and* quarter-thickness
   $\text{Log (C.R.)} = -0.0696 - 0.813 \log t$
2. For spray quenching.
   mid-thickness
   $\text{Log (C.R.)} = 1.202 - 1.007 \log t.$
   quarter thickness
   $\text{Log (C.R.)} = 1.285 - 1.018 \log t$

A relationship can be shown between the Jominy End Quench Distance and the plate thickness showing the same cooling rate at its center. This relationship is shown in Fig. 3. If Jominy curves are available for a steel, then a rapid estimate of the as-quenched tensile strength for section sizes up to $3^1/_2$ in. can be made.

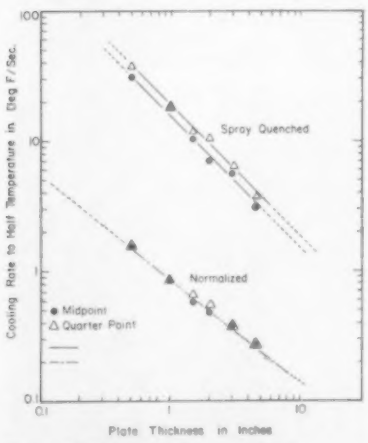


Fig. 2—Half-temperature cooling rates in spray-quenched and normalized plates up to 10 in. thick

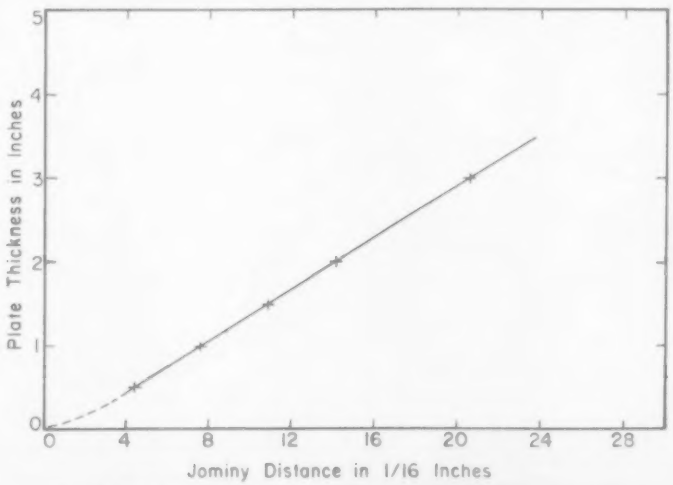


Fig. 3—Relation between Jominy end-quench distance and spray-quenched plate with same cooling rate at the midpoint

Response of Plain Carbon Steels

For the initial study of spray quenching as a means of improving mechanical properties, two low-carbon steels were selected, similar in composition except for their deoxidation practices. The compositions of the two steels (ABS-B and ABS-C) are given below:

	Steel	
	ABS-B, %	ABS-C,
C	0.19	0.15
Mn	0.73	0.76
P	0.012	0.010
S	0.032	0.026
Si	0.04	0.24
	Semikilled	Killed, fine grained

These steels were tested in $^1/_2$ and 1 in. plate thicknesses. The selection of these steels permitted an evaluation of the response of both killed and semikilled low-carbon steels. Although these carbon steels are not pressure-vessel steels, they are similar to certain pressure-vessel steels (ABS-B to A285 Grade B and ABS-C to A201 Grade A).

Austenitizing was performed at 1650° F for 1 hr per in. of plate thickness. After austenitizing, the steel was either spray quenched or normalized. Spray quenching was executed by the technique followed in the determination of cooling rates. Some additional tests were conducted on the ABS-B steel austenitized at 1800 and at 1950° F.

Mechanical Tests

An important part of this program was to detect any differences in properties from center to surface. Therefore, the location of the test specimens, as well as the types of tests to be performed, were chosen accordingly. This testing program was set up as follows:

Tension Tests

1. Strip tests: (*a*) Full thickness; (*b*) 0.197 in. thick from surface; and (*c*) 0.197 in. thick from mid-thickness of plates 1 in. thick.
2. 0.252 in. diam tests: (*a*) Center of $^1/_2$-in. plate; and (*b*) Quarter-thickness of 1-in. thick plate.
3. Welded joint efficiency tests.

Charpy V-notch Tests

1. Full size: (*a*) Center of $^1/_2$-in. thick plate; and (*b*) Quarter-thickness of 1-in. thick plate.
2. Half-width (0.197 x 0.394 in.): (*a*) Surface; and (*b*) Mid-thickness of 1-in. thick plates.

Drop Weight Tests

1. 2 x 5 in. $^1/_2$-in. thick plate.
2. $3^1/_2$ x 12 in. on 1-in. thick plate.

It was hoped with this series of tests to uncover any property differences occurring across the thickness of the plate. In addition to the tests listed above, hardness traverses were taken on the cross-sections of heat-treated plates.

Results of Mechanical Tests

The results of the hardness traverses are summarized in Fig. 4. The variations in hardness across the normalized plates can be attributed to compositional nonuniformity. It is apparent that spray quenching produced a uniform increase in hardness across the thickness of the plate. This finding agrees with the results of the cooling rate study wherein the mid-thickness and quarter-thickness cooling rates were essentially identical for spray quenched or normalized $^1/_2$-in. thick plates.

The cooling rate near the surface

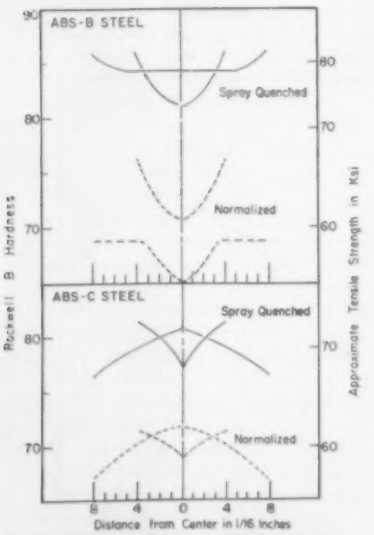


Fig. 4—Survey of hardness variations across spray quenched ABS-B and ABS-C steels of $^1/_2$ and 1-in. thickness

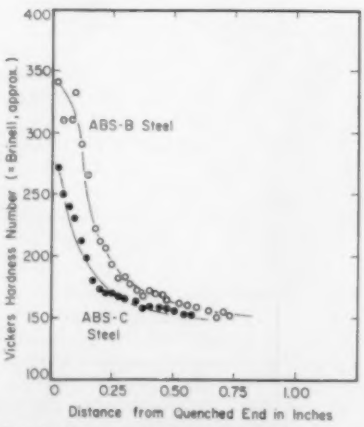


Fig. 5—End-quench hardenability of the ABS-B and ABS-C steels

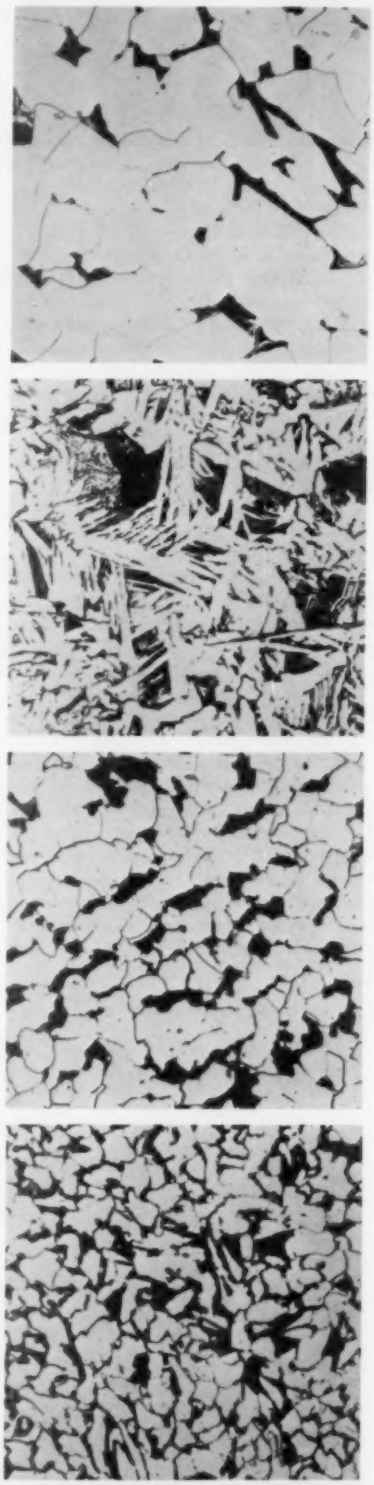


Fig. 6—Comparison of microstructures produced in ABS-B and ABS-C steels by spray-quenching and by normalizing

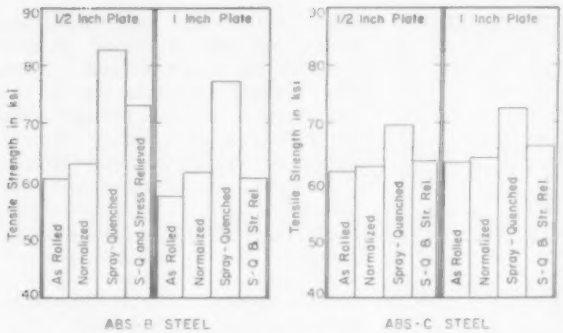


Fig. 7—Effect of heat treatments on the tensile strengths of ABS-B and ABS-C steels

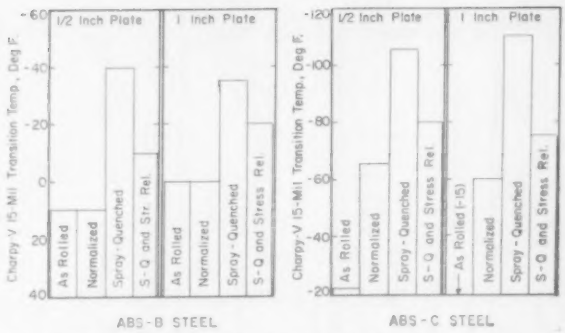


Fig. 8—Effect of heat treatments on the Charpy V-notch ductility of ABS-B and ABS-C steels

of the 1/2-in. thick plate was not fast enough to produce even partial martensitic hardening in these mild steels. The shallow hardening nature of these steels is further shown by the end quench test results presented in Fig. 5. However, the cooling rates across the 1/2-in. sections were fast enough in spray quenching to produce microstructural refinement and an accompanying improvement in mechanical properties. Figure 6 shows the microstructures that were obtained for normalized and spray quenched ABS-B and ABS-C steels. A noticeable refinement of the ferrite grain size and reduction in its volume are apparent in the spray quenched samples. Both changes serve to improve notch ductility.

The results of the mechanical tests are given in Table 2 for the ABS-B and ABS-C steels. In general, the tension test results indicate that spray quenching produced a significant improvement in the tensile strengths of the steels. Moreover, the improvement in strength was achieved with only a slight loss in percent elongation. The greatest gain was registered for the ABS-B steels where improvements (as-rolled compared to spray quenched) approached 25%. Stress relieving after spray quenching resulted in a loss of strength and a gain in elongation as compared to the as-quenched conditions. The loss in strength after stress relieving was greater in the ABS-B steel. The results of the tensile tests performed on welded plates showed essentially a 100% efficiency for all tests.

The notch toughness, as measured by the Charpy V-notch test, was greatly improved in both steels by spray quenching. Transition temperature decreases (based on the 15 mil lateral expansion criterion) of 50 and 35° F were recorded for 1/2- and 1-in. thick ABS-B steel plates respectively. ABS-C steel was similarly improved. Stress relieving after spray quenching produced a slight decrease in toughness.

The drop weight NDT proved to be insensitive to the heat treatments. Essentially no difference was noted for any of the heat treatments studied.

The changes in mechanical properties discussed above are presented in bar graphs. Figures 7 through 9 present the changes in tensile strength and notch ductility introduced by heat treatment.

Effects of Higher Austenitizing Temperatures

The ABS-B steel was austenitized at two higher temperatures—1800° F and 1950° F—in addition to the 1650° F temperature. These higher temperatures were studied in order to examine the possible benefits of direct quenching from hot rolling.

Table 2—Mechanical Test Results

	Tensile properties*									Notch ductility			
	Full size		0.252-diam		Welds	Center strip		Surface strip		Drop wt.,	Charpy, 15 mil		
Condition	T.Str.	% El.	T.Str.	% El.	T.Str.	T.Str.	% El.	T.Str.	% El.	NDT	0.394	Center	Surface
1/2-in. ABS-B Steel													
AsR	59.2	45.5	60.4	34	66.8	...	...	61.1	33.5	−20	+10	...	−30
Norm.	60.3	48.5	63.0	32	61.3	...	...	62.2	35	−20	+10	...	−30
S.Q.	72.9	39	82.7	29	74.0	...	...	74.9	26	−10	−40	...	−55
S.Q. and S.R.	...	...	73.0	33	...	...	...	71.6	27	0	−10	...	−40
1-In. ABS-B Steel													
AsR	56.2	48	57.4	35	59.9	53.5	36.5	58.9	35	+10	0	−40	−15
Norm.	56.8	50	61.6	34	60.2	56.0	37	58.6	36	+20	0	−25	−15
S.Q.	70.6	38	77.1	27	69.0	70.5	32	70.7	29	+10	−35	−60	−35
S.Q. and S.R.	59.3	48	60.5	34	60.0	59.3	38	59.2	36	+10	−20	−55	−25
1/2-in. ABS-C Steel													
Norm.	61.8	51	62.5	36	63.1	...	...	63.2	37.5	−60	−65	...	−85
S.Q.	70.2	44.5	69.6	35.5	70.4	...	...	70.8	32.5	−60	−105	...	−155
S.R. and S.R.	...	...	63.4	37	...	...	...	65.6	33.5	−80	−80	...	−110
1-in. ABS-C Steel													
Norm.	62.8	47.5	64.5	35	65.5	64.4	34	62.8	34	−20	−60	−80	−85
S.Q.	69.9	47.5	72.7	32.5	72.1	71.0	33.5	70.4	32	−30	−110	−130	−140
S.Q. and S.R.	64.7	51	66.0	35	66.1	65.6	36	64.4	36	−30	−75	−105	−100

*T.Str., tensile strength; El., elongation.
NOTES: Tensile strengths are in ksi; Charpy and drop-weight transition temperatures are ° F.; center and surface Charpy tests were 0.197 in. wide: center and surface strip tensile tests were 0.197 in. thick.

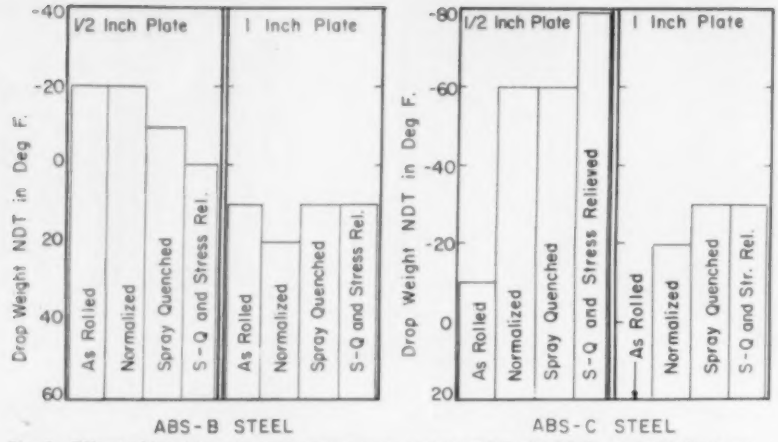


Fig. 9—Effect of heat treatments on the drop-weight NDT of ABS-B and ABS-C steels

The results of this investigation are summarized in Table 3. The Charpy and drop weight tests showed that the higher austenitizing temperatures, which coarsened the grain size, raised the transition temperature of the steel.

In general the data showed that treatments from high austenitizing temperatures were harmful to the properties of these carbon steels. Moreover, the advantages of spray-quenching over normalizing in improving notch ductility were lost when the treatment temperature was raised above 1650° F.

Summary

The results of the investigation reported herein can be summarized as follows:

1. A survey was made of commercial spray quenching. A spray rate of 0.3 cu in. of water per sq in. of surface per side per sec was found to be a practical value for production spray quenching.

2. For the above spray rate, cooling rates were measured at the mid-point and quarter-point of various section sizes from $^1/_2$ to $4^1/_2$ in. thicknesses. From the observed cooling rate, equations were derived to permit an approximation of the cooling rate (in ° F per sec) at the mid-thickness and quarter-thickness positions of plate thicknesses from $^1/_2$ to 10 in. These equations, based on the half-temperature cooling rate, are as follows for spray quenching:

(a) mid-thickness
$$\text{Log (C.R.)} = 1.202 - 1.007 \log \text{thickness}$$
(b) quarter-thickness
$$\text{Log (C.R.)} = 1.285 - 1.018 \log \text{thickness}$$

In addition an equation was derived for air-cooling. Because of the similarity in cooling rates between the mid-thickness and quarter-thickness positions one equation suffices for both locations:

$$\text{Log (C.R.)} = -0.0696 - 0.813 \log \text{thickness}$$

3. A relationship was developed between the Jominy end-quench distance and the plate thickness which exhibits an equal cooling rate at its mid-thickness. From this, a rapid approximation of the as-quenched tensile strength for plate sections up to $3^1/_2$ in. can be obtained from an end-quench test.

4. Spray quenching raised the strength of ABS-B and ABS-C steels in $^1/_2$ and 1 in. thicknesses. Because of its greater hardenability, the ABS-B steel showed a greater increase (25%) in tensile strength than did the ABS-C (11%). Stress relieving after spray quenching, however, reduced the strength level essentially to that of the normalized plate.

5. Both steels were improved in notch ductility by over 35° F through spray quenching.

6. The drop weight test NDT did not show the benefits of spray quenching over normalizing indicated by the Charpy tests.

7. A metallographic study of these steels showed that spray quenching produced a noticeable refinement of the ferrite grain size and a reduction in its volume. No martensitic hardening was observed in the spray quenched sections. This result was predictable from end-quench tests.

8. High austenitizing temperatures proved harmful to the notch ductility of the ABS steels. Raising the austenitizing temperature from 1650 to 1950° F resulted in an increase of 50° F in the transition temperature of ABS-B steel.

References

1. Gross, J. H., Kottcamp, E. H., and Stout, R. D., "Effect of Heat Treatment on the Microstructure and Low Temperature Properties of Pressure-Vessel Steels," THE WELDING JOURNAL, 37 (4), Research Suppl., 160-s to 168-s (1958).

2. Rubin, A. I., Gross, J. H., and Stout, R. D., "Effect of Heat Treatment and Fabrication on Heavy-Section Pressure Vessel Steels," WELDING JOURNAL, 38 (4), Research Suppl., 182-s to 187-s (1959).

Table 3—Mechanical Test Results (ABS-B Steel Austenitized at Elevated Temperatures)

Condition	Tensile properties: Full Size, Tensile strength	Full Size, Elongation, %	0.252 diam, Tensile strength	0.252 diam, Elongation, %	Surface Strip, Tensile strength	Surface Strip, Elongation, %	Center Strip, Tensile strength	Center Strip, Elongation, %	Welds, Tensile strength	Notch ductility: Drop Wt., NDT	Charpy, 15 mil, 0.394	Charpy, 15 mil, 0.197 Center strip	Charpy, 15 mil, 0.197 Surface strip
$^1/_2$-in. ABS-B													
1800° F													
Norm.	...	..	58.4	31.5	60.5	35.5	...	..	...	−20	+5	...	−17
S.Q.	...	..	68.2	35	77.6	20.5	...	..	...	+10	−16	...	−10
1950° F													
Norm.	...	..	60.6	34	60.6	34	...	..	...	−10	+14	...	−10
S.Q.	...	..	80.4	23.5	75.8	26.5	...	..	...	+40	+10	...	−9
1-In. ABS-B													
1800° F													
Norm.	56	48	57.2	36	58.1	37	54.8	37	61.6	+20	0	−10	−5
S.Q.	69	42	60.7	32	69.8	29	68.9	30	75.8	+60	−15	−55	−15
1950° F													
Norm.	56.3	49	58.2	36	60.5	35	57	33	58.2	+30	+10	−10	−10
S.Q.	82	30	74.1	26	82.0	21	81	22	73.8	+60	−10	−65	−60

Sheet Fracture Toughness Evaluated by Charpy Impact and Slow Bend

Precracked Charpy specimens provide economical, sensitive, reproducible and meaningful test for easy evaluation over wide temperature range and different loading rates

BY GEORGE M. ORNER AND CARL E. HARTBOWER

ABSTRACT. Previous work at Watertown Arsenal Laboratories demonstrated that high-strength sheet materials in thicknesses down to about 40 mils can be satisfactorily tested by Charpy impact or slow bend using an edge-notch specimen similar to the standard V-notch Charpy specimen except for thickness. By comparing the Charpy with results from other fracture tests, it was found that qualitative values could be expected for tough and moderately tough materials. In brittle materials, however, the Charpy results were found to be anomalously high due to elastic-energy losses which, in the more extreme cases, overshadowed the total energy absorbed from all other sources combined. Later work showed that if sheet Charpy specimens were precracked by a reverse bending technique or by fatigue, quantitative fracture toughness values were obtainable even in brittle materials. The results from precracked Charpy sheet tests are expressed in terms of energy to propagate per unit of crack area (W/A). Expressed as in-lb/in.^{2}, the W/A value is comparable with G_c and can be related to critical crack length at any desired stress level directly from the Griffith equation.

Excellent correlation was demonstrated between G_c and W/A in tests on a variety of high-strength aluminum sheet alloys where all tests were conducted in one laboratory and the Charpy tests were run in slow bend to eliminate the strain-rate variable. Qualitative correlation with edge-notched tensile tests conforming to the recommendations of the ASTM Committee on Fracture Testing was also observed, except in the tougher materials where the tensile test was insensitive to variations in fracture toughness.

The effect of strain rate on fracture toughness in high-strength sheet materials has received comparatively little attention. This is because most of the tests in common usage require stress and sometimes critical-crack-length measurements which cannot easily be obtained under impact rates of loading. The Charpy tests, on the other hand, can be evaluated easily in either slow bend or impact; thus, the effect of impact loading on fracture toughness can be readily assessed. Charpy slow bend and impact tests were conducted on a number of different steel, titanium and aluminum sheet materials. It was indicated that many high-strength sheet materials exhibit enhanced fracture toughness properties under impact loading conditions but that there are some important exceptions. For example, the all-beta B120VCA titanium alloy in the solution-treated condition exhibited much greater toughness in slow bend than in impact. Several other materials showed better fracture toughness at slow rates of loading, but the effects were much less pronounced. The validity of these findings was corroborated by lateral expansion measurements in the aluminum materials and by fracture appearance in steel; i.e. the differences in energy to fracture between slow bend and impact were attended by corresponding differences in deformation and in the percentages of shear in the fracture surfaces.

GEORGE M. ORNER and CARL E. HARTBOWER are with the Research Div. of Manufacturing Laboratories, Inc., Cambridge, Mass. The research described herein was done while the authors were with the Watertown Arsenal Laboratories, Watertown, Mass. (The opinions or assertions contained herein are the private ones of the authors and are not necessarily to be construed as official or reflecting the views of the Department of the Army.)

Paper to be presented at the AWS National Fall Meeting in Dallas, Tex., during Sept. 25–28, 1961.

Introduction

Catastrophic crack-propagation failures occurring at or below design stresses in high-strength sheet structures have become so commonplace that the necessity for standardizing tests for evaluating sheet for susceptibility to this type of failure is well recognized. Two committees, the ASTM Committee on Fracture Testing of High-Strength Sheet Materials and the Aerospace Industries Association ARTC Project W-97 (Standardization of the Test Procedure for Tear Resistance of Metallic Sheet Materials), have been set up expressly for this purpose. Tentative recommendations for a screening type of test have been published by the ASTM Committee.[1]

Most of the tests in current use involve slow stressing of sharply notched tensile specimens. Maximum load and crack length at the onset of fast fracture are generally the data sought. Although pulling-head speeds in these tests are generally low, strain rates at the root of the notches are high because of the sharpness of the notches used; and since most high-strength materials are thought to be relatively insensitive to strain-rate variations, it is considered by some investigators that there may be little difference between static and dynamic test results.[2]

In dynamic (impact) tests, the most readily obtained criterion for evaluating performance is the energy to fracture. In conventional Charpy testing, the impact energy values are an integration of the energy to initiate and to propagate cracking and sundry energy losses; thus, a quantitative evaluation is not possible except empirically by comparison with the results from a more pedigreed test (e.g., the G_c centrally notched tensile test).

In a previous report[3] it was demonstrated that Charpy tests can be run on edge-notched sheet specimens* in thicknesses down to 0.040 in. without buckling. Furthermore, it was shown that in ductile sheet specimens (e.g., in sheet steel specimens showing 50% or more fibrous

* V-notched Charpy impact specimens of conventional dimensions except for specimen width which is the thickness of the sheet.

Table 1—Aluminum Alloys Investigated and Their Tensile Properties

Alloy	0.2% yield strength, ksi	Tensile strength, ksi	Elongation, % in 2 in.
2024 T3	45.7	67.6	19.0
2024 T81	61.1	69.5	9.5
2024 T86	71.0	76.4	6.8
6061 T6	38.3	45.6	15.0
7075 T6	79.4	84.4	11.5
7178 T6	77.8	89.0	14.3
X7079 T6	71.6	81.7	10.8
X2020 T6	72.7	80.5	7.0
X2219 T6E46	50.7	67.2	12.5

area in their fracture surfaces) there was a fair qualitative correlation between Charpy and G_c test results. In the case of brittle specimens, however, a gross lack of correlation was observed, with the Charpy specimens giving higher energy values than would be expected from the G_c results. This lack of correlation was attributed to elastic energy losses.

One object of the work described in this report was to develop the Charpy test further for measuring fracture toughness in high-strength sheet by eliminating, if possible, the anomalously high energy values that occur when brittle specimens are tested. Another object was to investigate further the correlation between the Charpy and other tests (G_c in particular). Moreover, both slow-bend and impact tests were planned on a number of materials in a limited investigation of the effect of rate of loading on the fracture toughness of high-strength sheet materials.

High-strength steel, titanium and aluminum sheet materials were tested. G_c values for titanium and aluminum were determined at the Watertown Arsenal Laboratory. In steel, most of the G_c tests were conducted either at the Naval Research Laboratory, the Naval Proving Ground, the Naval Weapons Plant of the United States Steel Corp. Coupons for Charpy testing were generally machined from broken G_c specimens.

Experimental Procedures

Materials

Much of the steel, as indicated above, was obtained in the form of broken G_c specimens from various Government installations and from the United States Steel Corp. Data on the physical properties of these steels, together with data for most of the titanium alloys may be found in a previous paper by the authors.[3] The aluminum sheet alloys were obtained through the courtesy of Alcoa and are listed in Table 1 together with their tensile properties as determined at Watertown Arsenal Laboratories.

One phase of this study involved a cooperative effort between the Metals Joining Branch of Watertown Arsenal Laboratories and the Applied Physical Metallurgy Section of the Naval Research Laboratory. The objective was a comparison between the results of the NRL fatigue-cracked tensile test and the sheet Charpy test using identical materials. Samples from seven titanium sheets were supplied by Watertown Arsenal for the study. All of the sheet was from the DOD Titanium Alloy Sheet Rolling Program as investigated under Air Force sponsorship.[3] In the case of two of the sheets (Ti-4Al3Mo-1V heat M8012 and Ti-2.5Al-16V heat B22117), the WAL and NRL test specimens were heat treated simultaneously in Pyrex tubes backfilled with helium. The Ti-6Al-4V sheets were tested in the as-received (mill-annealed) condition. The tensile specimens from one sheet of Ti-4Al-3Mo-1V (heat M8011) were aged in vacuum at NRL; whereas, the Charpy specimens were aged in helium at Watertown Arsenal.

The Naval Research Laboratory provided samples (approximately 1 sq ft) of several steels and one titanium alloy that were either previously investigated or currently under investigation with their crack-propagation tensile test. Samples tested by fatigue-precracked Charpy at Watertown Arsenal are shown in Table 2. These materials (shipped to Watertown Arsenal in the annealed condition) were given the same heat treatment as used at the Naval Research Laboratory.

Table 2—Materials Tested by Fatigue-precracked Charpy

Type	Heat	Thickness, in.	Reference
410 stainless	Steel "A"	0.039	4
AM-350	AL 79650	0.063	...
AMS-6434 (air-melted)	AL 04104	0.063 0.125	5
AMS-6434 (consutrode)	AL 22138-3	0.063	5
Ti-4Al-3Mo-1V	Heat M8172	0.063	...

Testing Procedures

Charpy impact tests were conducted on a subsize Charpy machine with a maximum capacity of 16 ft.-lb. This machine was originally designed for testing plastics and has been considerably modified to give it the stiffness necessary for impact testing metals. Slow bend tests were conducted on a conventional tensile testing machine fitted with tup and anvils whose geometry essentially duplicated that of the tup and anvils of the Charpy machine.

Two techniques were used for precracking Charpy specimens. In testing low and medium-strength constructional materials, an easily executed variation in the standard technique for testing Charpy impact specimens has been developed which permits a separation of the crack initiation and crack propagation stages of the fracture process.[6] The technique requires "initiation" of a crack by means of a low-energy blow and propagation of the crack by a full-capacity blow of the impact machine pendulum. Obviously, in brittle materials it would be very difficult, if not impossible, to initiate cracks by direct loading of the specimens without causing complete fracture of the test specimen. However, Mylonas and his associates[7] have demonstrated that by precompressing notched tensile specimens of ship plate, brittle fracture can be initiated at low net section stresses. It was hypothesized that if a notched Charpy specimen were bent slightly with the notch in compression, upon unloading, the residual tension stresses resulting from the local plastic compression which occurred at the root of the notch during loading would cause a crack to initiate in materials embrittled by cooling. Experiments in which notched sheet Charpy specimens were bent in reverse at −196° C (by striking a low-energy blow against the notched edge of each Charpy specimen) showed that cracks could, indeed, be initiated without propagating through the specimens. In brittle specimens, precracking was observed to greatly lower the energy necessary to fracture; whereas, in the more ductile materials the energy-to-fracture was lowered a comparatively small amount. Unfortunately, cracking generally initiated a little to one side of the notch root and did not propagate at right angles to the specimen axis. The further these cracks propagated, the further their direction of propagation deviated from the normal, until eventually the cracks nearly paralleled the specimen axis. Thus, the energy

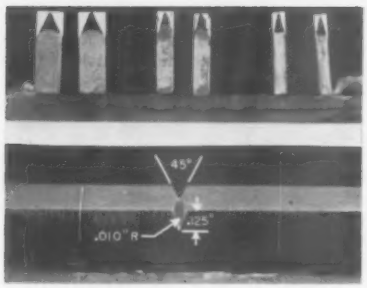


Fig. 1—Taper notched Charpy specimen and typical ink-stained cracks

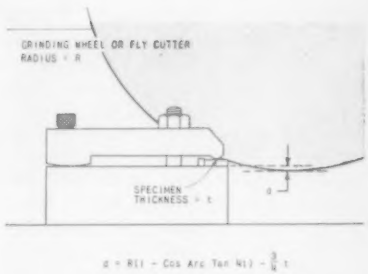
required to form the crack was critical, and even when relatively straight-cracks were formed, subsequent propagation often deviated from the normal.

The difficulty of controlling crack direction was overcome by use of the notch type illustrated in Fig. 1. Note, in the lower photograph, that there are two opposing notches which just meet in the center of the top edge of the specimen. The geometry of the notch itself is the standard Charpy 10-mil radius V notch. The notch is designed so that if the precrack is $^1/_{16}$-in. deep, the remaining cross section is approximately equal to that of the standard Charpy V-notched specimen. Typical ink-stained* cracks are illustrated in the upper portion of Fig. 1. The method used for cutting these notches is illustrated in Fig. 2. The simple holding fixture in Fig. 2 is equipped with stops for accurately locating the specimens. Previous to notching, all specimens are ground to the same length and, as the notches are cut exactly in the center, after the initial set up, no further adjustments are necessary. All notches are cut 0.125-in. deep (Fig. 1) and are of the standard Charpy V geometry, i.e., a 45 deg. included angle and a 10-mil root radius. The angle that the notch roots make with the transverse axis of the specimens varies with specimen thickness. The correct angle is obtained by specifying the vertical distance between the lowest point on the grinding wheel and the horizontal surface of the fixture against which the specimen is clamped.

In most of the steel and titanium materials tested, the deformation occurring as a result of the precracking operation was small (normally the mid-span plastic deflection was of the order of 2 mils), particularly in high-strength relatively brittle specimens. The reverse-blow energy used for cracking a 0.1-in. thick steel specimen was about $2^1/_2$ ft-lb. Thinner specimens usually were found to require less energy per unit of thickness than thicker specimens.

Another technique used for precracking involved fatigue. A simple device for gripping the specimens was made to fit the bending fixture of a Baldwin S-F-IU Universal fatigue testing machine. The reciprocating load was adjusted to stress the specimens equally in both directions. Loads were set so that a $^1/_{32}$-in. deep crack would be formed at the apex of the notch in approximately 1 min. Since the time required to start a fatigue crack varied considerably even between presumably identical specimens, some way to indicate the depth of the fatigue crack was required. The design of this fatigue machine is such that the reciprocating load applied to a specimen is independent of the amplitude of the vibration. Thus, when a crack is formed, the resulting loss of stiffness in the specimen is reflected as a small increase in the amplitude of vibration which, in these tests, amounted to approximately 5% of the total amplitude. The increment of vibration amplitude was measured with a dial indicator. The dial indicator, which is standard equipment on these machines, is mounted just below the vibrating frame and is intended for use in presetting static loads on specimens when so desired. The movement of the dial indicator plunger was stiffened by placing a soft wood wedge between its lower extension and the post on which the dial indicator is mounted. With the machine running, the plunger was pushed gently upward to make contact with the vibrating frame at the lower end of its travel. When the fatigue crack formed and started to propagate, the increase in the travel of vibrating frame was measured directly on the dial indicator. An increment of 1 mil for steel specimens and $1^1/_2$ mils for titanium and aluminum specimens was found to indicate the formation of a fatigue crack approximately $^1/_{32}$-in. deep.

The crack propagation specimen used by the Naval Research Laboratory was a tensile specimen containing a central narrow slot, normal to the tensile axis, terminated at each end by a fatigue crack. The specimens were tested



$a = R(1 - \cos \text{Arc Tan } N) - \frac{3}{8}t$

Fig. 2—Method used for grinding taper notches in sheet Charpy specimens

at slow rates of loading, the load being applied by hardened pins passing through holes in the ends of the specimen. Both conventional tensile specimens and the crack-propagation specimens were tested over a range of temperature. In steel, the range tested was broad enough so as to bracket the full shear temperature (FST) which is defined as the lowest temperature at which the fracture of a crack-propagation specimen will be entirely of the oblique shear type.[5] In addition to fracture appearance, the nominal net fracture stress, defined as the maximum load divided by the product of the specimen thickness and the difference between the specimen width and the *initial* crack length, was used as a measure of the mechanical fracture toughness. The resistance to fracture was alternatively expressed in terms of a quantity having a less restricted significance than the net fracture stress, viz., the fracture toughness, K_c, proposed by G. R. Irwin as a consequence of his stress-analysis approach to the problem of fracture.[1] Whereas net fracture stress is a function of specimen width and crack length, in principle and subject to certain requirements for a satisfactory test, K_c is independent of specimen dimensions other than thickness. The crack-propagation tensile testing was done at the Naval Research Laboratory; all K_c values were calculated by the indirect method (i.e., no "ink stain" values were given).

Experimental Results

NRL Tensile and V-notched Charpy Impact Tests

The initial phase of the cooperative program between NRL and Watertown Arsenal Laboratories involved three alloys from the DOD Titanium Alloy Sheet Rolling Program. The Charpy data for these materials were obtained early in the program before the advantages

* A drop of India ink containing a wetting agent is applied to the root of the notch after the low-energy reverse blow has been struck. The excess ink is wiped from the notch and 24 hr is allowed for the ink to dry.

of precracking were realized. Therefore, conventional 0.010-in. radius V-notches were used. The crack-propagation test specimen used by the Naval Research Laboratory was 1.5-in. wide with a 0.5-in. fatigue-cracked slot. Four heats of Ti-6Al-4V were tested in the as-received (mill-annealed) condition (Fig. 3) and two heats of Ti-4Al-3Mo-1V and the one sheet of Ti-2.5Al-16V were tested in the solution - treated - and - aged condition (Fig. 4). In the crack-propagation tensile tests the materials were machined and fatigue cracked before aging.

The Charpy test, like the NRL test, showed the Ti-2.5Al-16V sheet to be decidedly inferior to the other sheets tested. Except in Ti-2.5Al-16V, NRL found the materials too tough for valid fracture toughness measurements with 1.5-in. wide specimens. Only at the lower temperatures were the K_{c3} data valid. Much larger specimens would have been required for accurate measurements at room temperature. Note, however, that the Charpy test was effective over the entire range of temperature. The difference between Ti-6Al-4V heats M4789 and M4790 (both 0.125-in. thick) is noteworthy; both the net fracture strength (notch/unnotch tensile ratio) and the Charpy curve indicated heat M4789 to be superior from the standpoint of transition temperature, whereas, K_{c3} as measured by the 1.5-in. wide tensile test showed relatively little difference between the two heats.

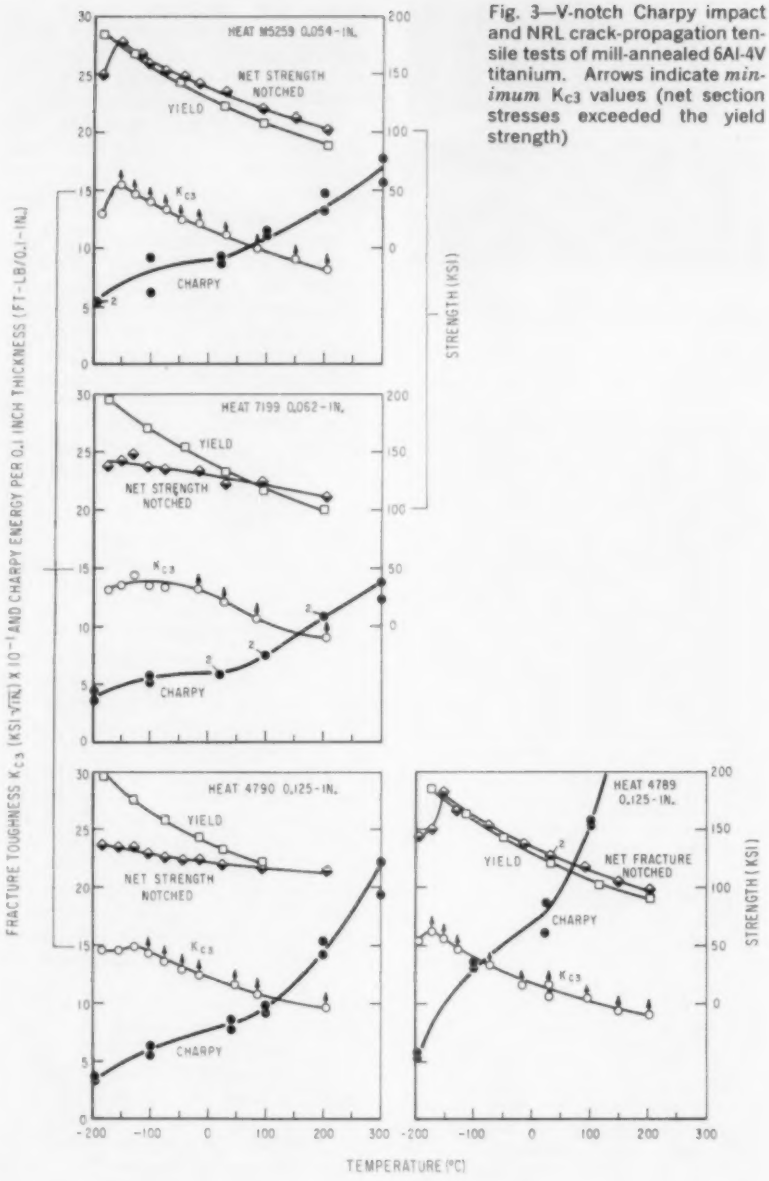


Fig. 3—V-notch Charpy impact and NRL crack-propagation tensile tests of mill-annealed 6Al-4V titanium. Arrows indicate *minimum* K_{c3} values (net section stresses exceeded the yield strength)

Sharp Machined Notches

In the earlier work at Watertown Arsenal Laboratories,[3] it was demonstrated that the V-notch Charpy impact test conducted on a single thickness of sheet is highly sensitive to such variables as heat treatment and composition type. Except in the most brittle steel and titanium sheet materials, V-notch Charpy impact test results correlate qualitatively with G_c test results, although considerable scatter was evident in the relationship (Fig. 5).

Although much of the scatter in the G_c-Charpy relationship may have been the result of anomalies in the G_c values,* the gross lack of correlation in the highly brittle materials cannot be attributed to scatter in the test results. It was hypothesized that the anomalously high Charpy values were the result of excess elastic energy stored in the specimens which was not absorbed during crack propagation. In other words, there was more elastic strain energy stored in the specimen at the instant of crack initiation than was required to complete the fracture of the specimen. To overcome this difficulty, it seemed necessary to greatly reduce the amount of elastic energy stored in the specimens. The only apparent way that this could be done was to lower the maximum load by using a much sharper notch.

In the earlier investigation at Watertown Arsenal Laboratories, the use of ultrasharp notches (1-mil radius or sharper) was purposely avoided, because such notches were considered difficult to cut reproducibly. However, in this phase of the investigation, specimens with 1-mil radius notches were prepared and tested using steels selected from the previous tests. Steels showing the best correlation were chosen to establish the slope of the curve, and steels showing the greatest anomalies were chosen to determine whether better correlation could be obtained with a sharper notch. The results of these tests are illustrated in the curves of Fig. 6. Note that although the brittle materials still show high

* Many of the G_C values reported were obtained from single tests. Moreover, the testing was done in four different Laboratories and the specimens ranged from 2 to 6 in. in width with various notch configurations.

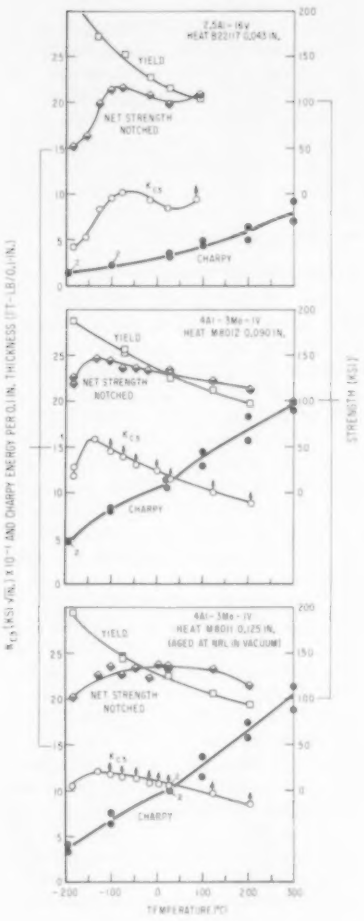


Fig. 4—V-notch Charpy impact and NRL crack-propagation tensile tests of aged 2.5Al-16 V and 4Al-3Mo-1V titanium alloys. Arrows indicate *minimum* K_{C3} values (net section stresses exceeded the yield strength)

Charpy energy values, the *gross* lack of correlation observed with a 10-mil radius was eliminated.

Cracked Charpy Notches (by Low Blow)

The possibility of initiating natural cracks in Charpy specimens was next considered. Specimens were cracked with the reverse low-energy-blow technique. A 2000 × photomicrograph of the tip of a reverse-blow-initiated crack is illustrated in Fig. 7. The sketched notch represents a 1-mil radius notch magnified 2000 times. Note the extreme sharpness of the natural crack compared with the 1-mil radius notch.

The effect of various notches on Charpy slow-bend curves for ×-200 air-hardening sheet steel tempered at 700° F is illustrated in Fig. 8. Note the large reduction in maximum load resulting from sharpening the notch from a 10-mil radius to a 1-mil radius, and the still greater reduction in maximum load when a natural crack was used. Note also, that the 10-mil radius *uncracked* taper notch was as effective in initiating fracture as the 1-mil radius V-notch. Concerning the energy absorbed during slow-bend as represented by the area under the load-deflection curves, note that with the standard 10-mil radius V-notch, most of the area (the cross-hatched portion under the load-deflection curve) represents elastic energy. This corresponds to approximately 1.4 ft-lb and represents the amount of elastic energy available to propagate the crack at the instant before fast fracture. From this curve there is no indication of how much energy was actually absorbed during

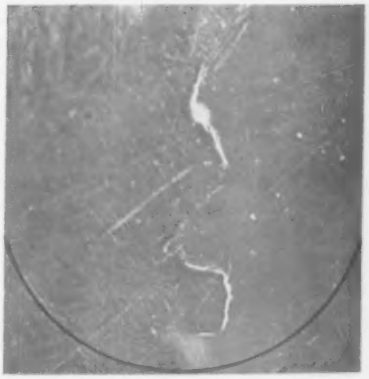


Fig. 7—Tip of reverse low-blow-initiated crack compared with 0.001-in. radius notch at X2000

crack propagation or how much was left over after fracture was completed. The total area under the load-deflection curve for the precracked specimen, however, indicates that a maximum of only 0.32 ft-lb was necessary to propagate the crack. Thus, with the standard 10-mil radius V-notch, of the 1.4 ft-lb of available elastic energy, only a small portion (approximately 0.32 ft-lb) was necessary for crack propagation. These results provide an explanation for the anomalous results obtained in the correlation between conventional Charpy energy and G_c (Fig. 5). Thus, the standard V-notched Charpy can give fictitiously high energy values when fracture is brittle (fast). With a cracked notch, however, propagation is slow and one obtains a direct measure of the energy required to propagate the crack.

The relationship between precracked Charpy impact energy and

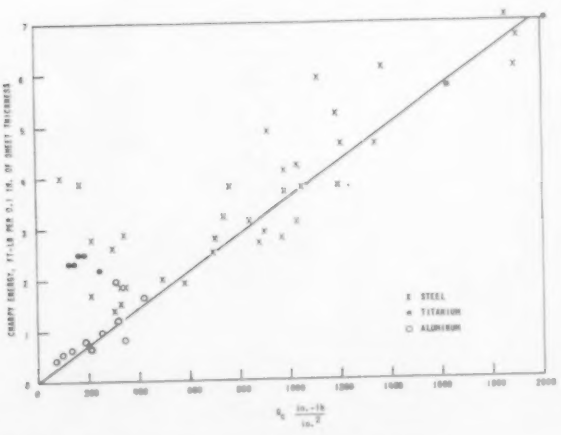


Fig. 5—Relationship between 0.01in. radius V-notch Charpy energy per 0.1-in. thickness and G_c

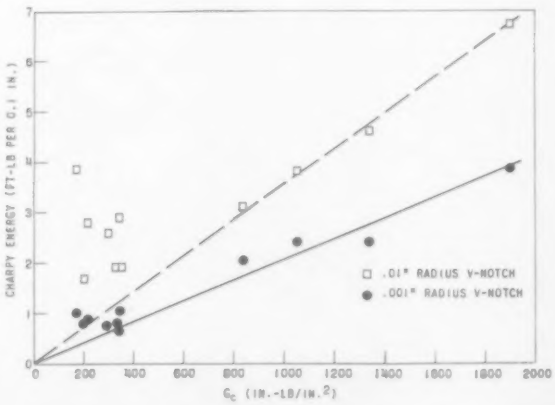


Fig. 6—Relationship between 0.01 and 0.001-in. radius V-notch Charpy energy per 0.1-in. thickness and G_c in selected steels

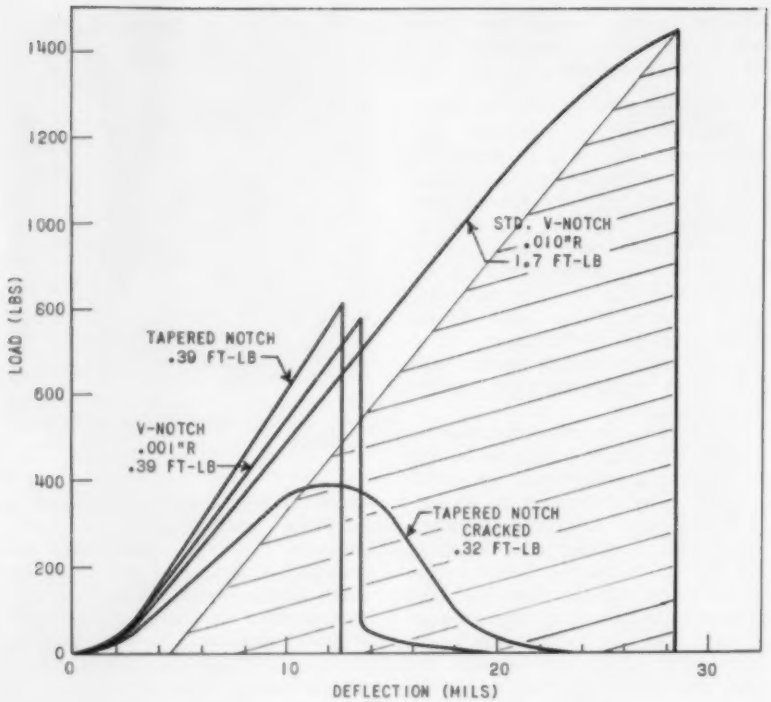


Fig. 8—Room-temperature load-deflection curves for several notch types in 0.080-in. thick X-200 steel sheet tempered at 700° F

G_c is illustrated in Fig. 9. The G_c values were not corrected for plastic strain occurring ahead of the crack extremity since, in many cases, insufficient data were available for the calculations. Charpy specimens were tested in triplicate and the values obtained are plotted as solid circles in groups of three. It should be recalled that the Charpy specimens were broken on impact. On the other hand, the G_c specimens were tested in slow tension and, furthermore, many of these materials were tested within their transition-temperature ranges where scatter is often high. Thus, perhaps, a closer correlation would not be expected. The 10-mil radius notch Charpy data, represented by the squares, were obtained from specimens cut from identical materials. The tabulated data for this illustration are presented in Table 3.

Figure 10 illustrates the effect of the cracked notch on the Charpy energy-temperature curve in one sheet steel. Note that with the 10-mil radius notched specimens, the increase in energy from the brittle range to the fully ductile range is only about 60% as compared with more than a 300% increase for the cracked specimens. The difference between the two curves in the low-temperature region is attributed to the fictitiously high energy values resulting from the excess elastic strain energy in the standard V-notched specimens.

Fatigue-cracked Charpy Notches

The taper-notch reverse-blow technique for precracking Charpy specimens was found to be unsuitable for aluminum and certain tough steel sheet that could not be sufficiently embrittled by cooling to liquid-nitrogen temperature for easy precracking. Cracks were formed only after severe deformation of the test specimens. Fatigue cracking was, therefore, investigated as an alternative method of precracking.

The fatigue method of precracking proved to be so simple and the results so reproducible that the reverse-blow method was discontinued altogether. Furthermore, for fatigue cracking, the more expensive taper notch was found to be unnecessary, i.e., the standard V-notch is used preparatory to fatigue cracking. Ink staining is also unnecessary, because the appearance of the fatigue-cracked surface is generally quite different from that of the subsequent fracture.

Heretofore, Charpy results have been expressed as energy absorbed per unit of sheet thickness (ft-lb/0.1 in.). With precracking, the Charpy test provides a direct measure of the energy required to propagate the crack and, therefore, the test results are best expressed

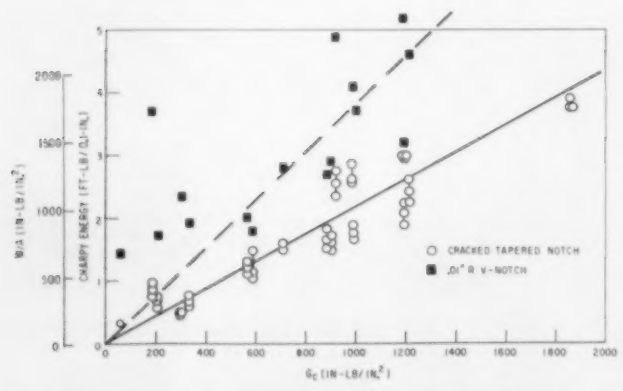


Fig. 9—Comparison between the Charpy-G_c relationship by standard Charpy V and cracked tapered notch in a variety of sheet steel materials

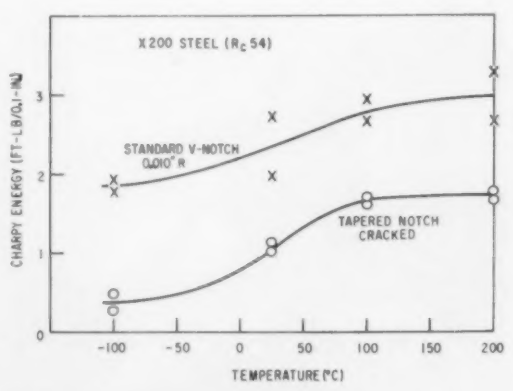


Fig. 10—Charpy curves for machined 0.01-in. radius V-notch and cracked tapered notch

Table 3—G_c and Precracked Charpy Impact Test Results in Steel Sheet Alloys (Room Temperature)

Steel	Gage, in.	Unnotched Yield, ksi	Unnotched Tensile, ksi	G_c Values in.-lb/in.²	G_c Values Source	Work Areea in-lb/in.²
H-11	0.125	223	323	53	WAL	114/106
X200	0.080	254.3	293.4	176	USS	370/350/310
Ladish[a]	0.100	228.2	300.1	204	NGF	294/266/250
X200	0.080	205.2	262.7	298	WAL	228/232/200
Ladish[a]	0.100	220.7	259.3	300	NGF	262/270/278
Ladish[a]	0.100	206.0	224.5	578	NGF	466/510/497
H-11	0.125	128.5	157.1	583	WAL	590/434/450
AMS 6434	0.190	214.3	258.0	706	NPG	620/628/676
AMS 6434	0.125	187.7	201.7	883	NPG	644/608/723
4335[a,b]	0.100	203.8	230.7	902	NGF	658/606/690
4335[a]	0.100	205.1	259.9	920	NGF	1106/1025/958
H-11	0.100	187.4	212.5	980	WAL	1055/1059/1163
AMS 6434	0.080	207.0	224.8	987	NPG	750/714/670
X200	0.080	213.6	244.0	1195	WAL	888/824/748
4335[a,b]	0.100	203.8	230.7	1190	NGF	1178/1194/1201
4335[a]	0.100	207.6	242.3	1210	NGF	972/911/1058
X4317	0.080	226.0	274.0	1860	USS	1560/1508/1492

[a] Orientation of smooth tensile specimens with respect to rolling direction is unknown, but in all cases the crack propagation direction for the G_c and Charpy data was the same.
[b] G_c and precracked Charpy taken in two directions with respect to major rolling direction.

in terms of energy per unit of crack area (i.e., Work/Area, in-lb/in.²) where the crack area is approximated by using the cross-sectional area under the Charpy V-notch, less the fatigue-cracked area.

Six of the steels supplied by the Naval Research Laboratory for the cooperative program were tested with a fatigue-cracked V-notch. Figures 11 and 12 show reproducibility of the Charpy test results and the marked differences produced by composition and processing variables. Note in particular the excellent toughness of the consumable - electrode vacuum - remelted heat of AMS 6434 (heat treated to a yield strength of approximately 200,000 psi) as compared with the airmelted heat.

The NRL crack-propagation tensile tests gave similar results (Figs. 13 and 14). The W/A values from the precracked Charpy tests are superimposed on the NRL illustration. Note that in AMS 6434 the FST occurred at −55° F in the 0.063-in. thick air-melted heat and at −170° F in the 0.063-in. consutrode heat. Results are not given in terms of K_c because, at the time that these tests were conducted, NRL was still using $^1/_2$-in. wide tensile specimens; consequently, the net fracture stress exceeded the yield strengths above the FST temperature. Note that the precracked Charpy transition range correlates temperaturewise with the tensile fracture-appearance transition. The figures adjacent to each plotted point of Charpy W/A data represent percent of oblique shear in the Charpy impact fractures.

G_c and precracked Charpy tests were conducted on the aluminum alloys listed in Table 1. The G_c tests were conducted in duplicate in 3-in. wide specimens and singly in 6-in. wide specimens. The test results are presented in Table 4. Note that with but one exception, the G_c results from the 6-in. wide

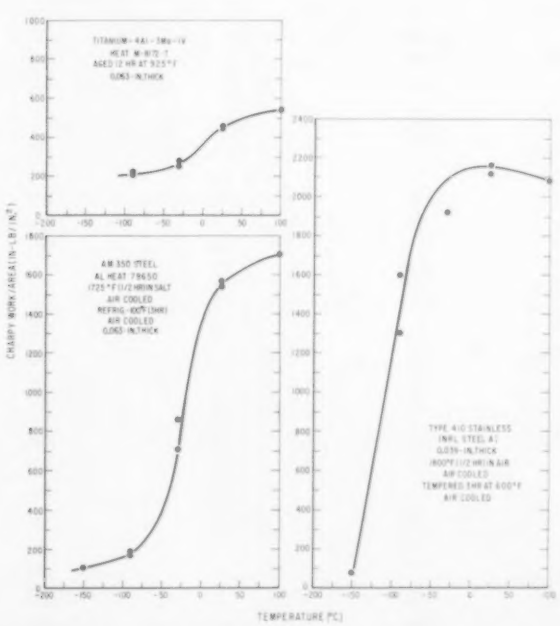


Fig. 11—Fatigue-cracked V-notch Charpy transition curves for NRL materials

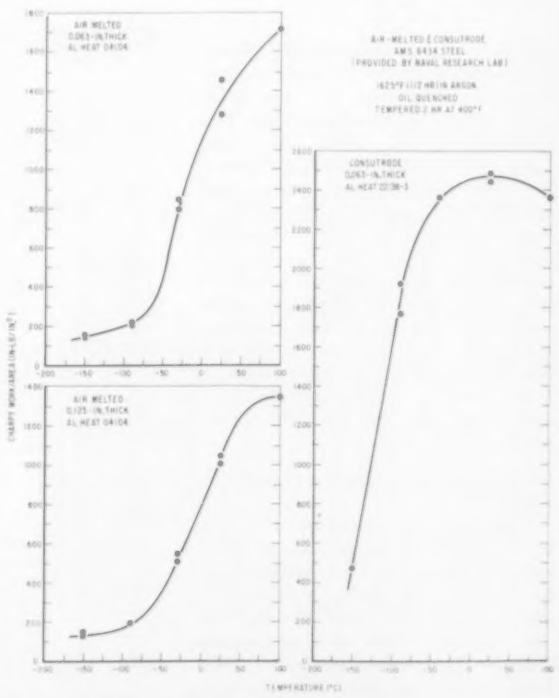


Fig. 12—Fatigue-cracked V-notch Charpy transition curves for NRL air-melted and consutrode AMS 6434

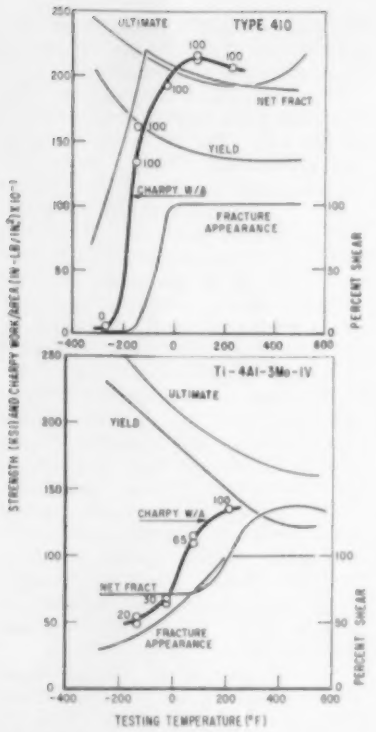


Fig. 13—Fatigue-cracked V-notch Charpy impact and NRL crack-propagation tensile tests of a 0.039-in. thick stainless steel and 0.063-in. titanium alloy. The NRL tensile specimen was 1/2-in. wide. The figures adjacent to the plotted Charpy data are percent oblique shear in the Charpy fracture surfaces

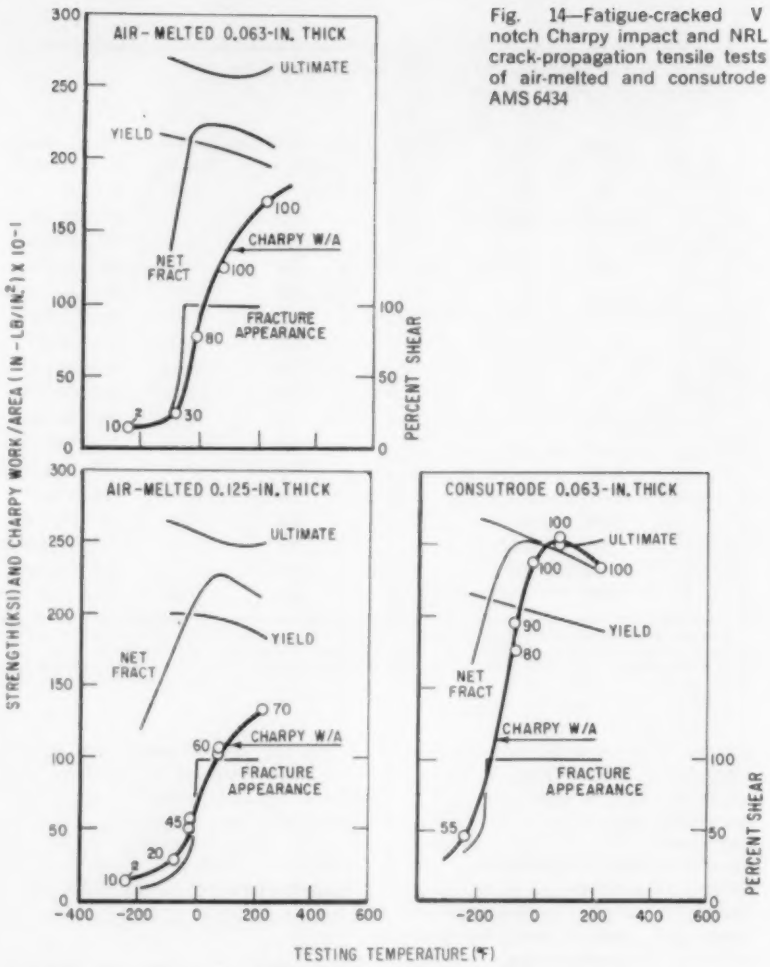


Fig. 14—Fatigue-cracked V notch Charpy impact and NRL crack-propagation tensile tests of air-melted and consutrode AMS 6434

specimens are appreciably higher (approximately 35% higher) than those obtained from the 3-in. wide specimens. The reason for this anomaly is not clear. In these tests the plastic correction factor for computing G_c was taken into account. A plot of the Charpy slow-bend data vs. G_c is presented in Fig. 15. Note that there is good correlation with the exception of one of the two toughest materials (2024T3). In these two toughest materials, the maximum net section stresses in the G_c tests exceeded the yield by approximately 30% and, therefore, the G_c values may not be valid.

Effect of Rate of Loading on Fracture Toughness

Few data are currently available on the fracture toughness of high-strength sheet at high strain rates because of difficulties in obtaining significant data from tensile impact tests. With the precracked Charpy specimen, however, fracture toughness data can be obtained directly from energy to fracture either in slow-bend or in

Table 4—G_c and Charpy Test Results in Aluminum Sheet Alloys

Alloy	Thickness (in.)	G_c (in.-lb/in.²) 3 in. wide	G_c (in.-lb/in.²) 6 in. wide	Fatigue cracked Charpy (in-lb/in.²) Slow bend	Fatigue cracked Charpy (in-lb/in.²) Impact
2024 T3	0.125	444	530	356	539
		441		334	563
2024 T81	0.125	235	298	155	241
		229		157	244
					216
2024 T86	0.125	103	100	74	144
		98			107
					115
7075 T6	0.125	159	220	113	130
		175		113	117
					125
7178 T6	0.125	108	145	88	90
		112		89	85
					117
X7079 T6	0.115	280	398	164	204
		252		190	176
					167
X2020 T6	0.125	50	86	48	86
		52		46	62
					61
X2219 T6E46	0.125	517	656	310	489
		447		306	416
					408

impact. Furthermore, direct comparison can be made between the results from the two rates of loading, although it is recognized that there may be small energy losses peculiar to the impact test that are not present in slow-bend testing. These losses, however, are believed to be generally insignificant. The largest energy loss in impact testing precracked specimens is probably the kinetic energy loss, i.e., the energy lost in accelerating the broken specimen halves to approximately the velocity of the Charpy machine hammer. In these tests the maximum velocity of the pendulum was 11.3 ft/sec. resulting in kinetic energy losses (maximum) of about 15 in-lb/in.^{2} for steel, 8 in-lb/in.^{2} for titanium and 5 in-lb/in.^{2} for aluminum. Obviously, these losses are insignificant except in very brittle materials.

Fracture-toughness data from impact and slow-bend tests on a variety of aluminum-alloy sheet materials are presented in Fig. 16. The data represent average values

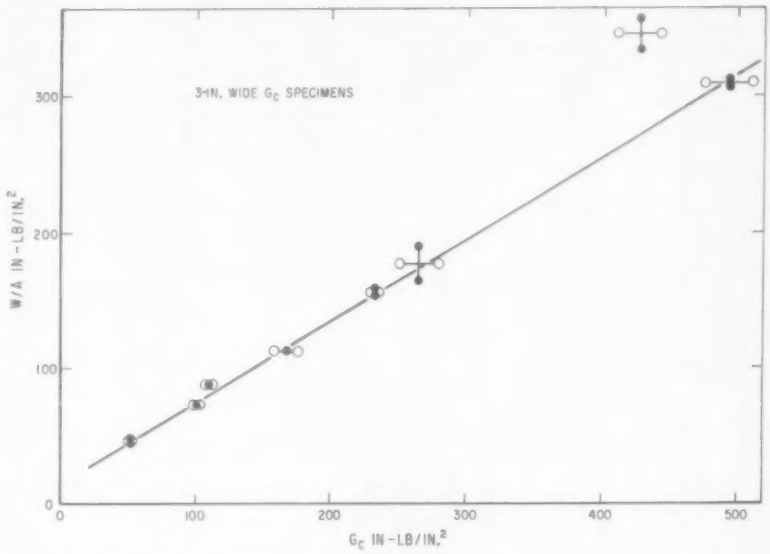


Fig. 15—Relationship between fatigue-cracked V-notch charpy slow bend and G_c in a variety of 0.125-in. thick aluminum alloys

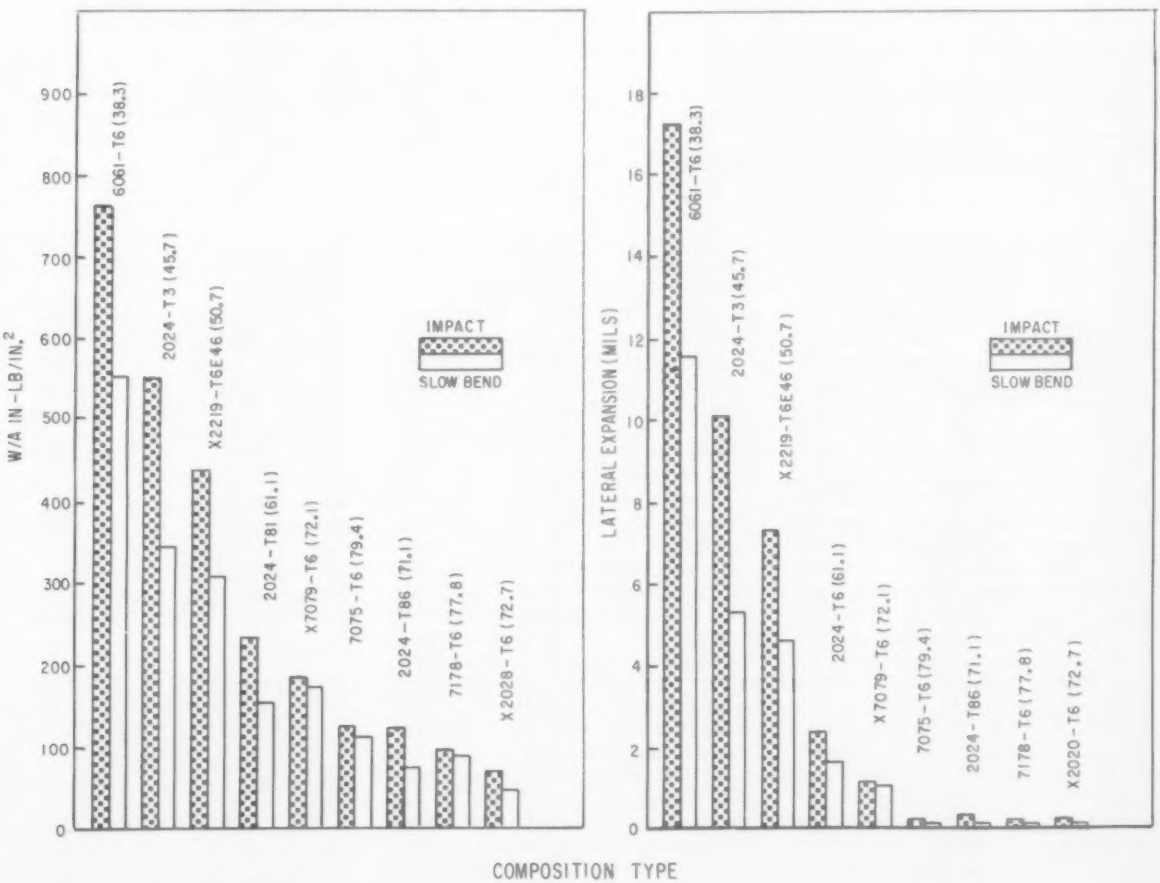


Fig. 16—Impact and slow-bend fatigue-cracked V-notch Charpy tests of aluminum sheet alloys. Note that the fracture toughness was greater in impact than in slow bend and that there is close agreement between W/A and lateral expansion. The 0.2% offset yield strength is given in Ksi after each alloy designation

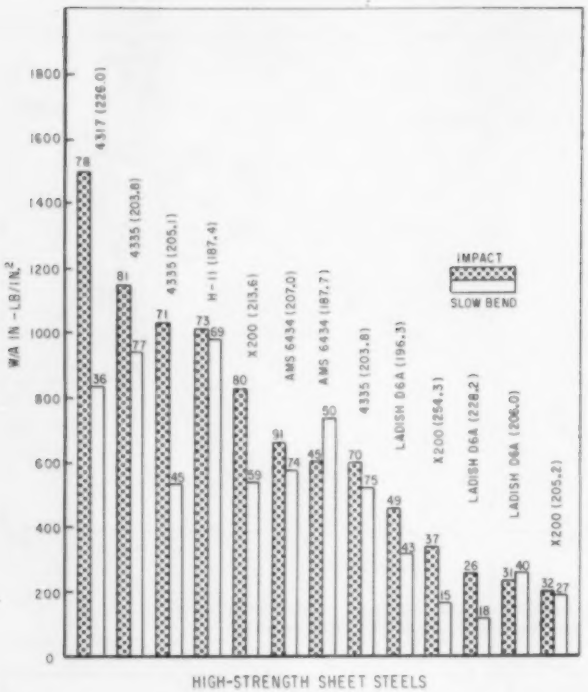


Fig. 17—Impact and slow-bend fatigue-cracked V-notch Charpy tests of a variety of sheet steel alloys. Note that with but two exceptions the fracture toughness was greater in impact. The figures above each bar are the percentages of oblique shear in the fracture surfaces measured at mid-depth. The 0.2% offset yield strength is given in Ksi after each alloy designation

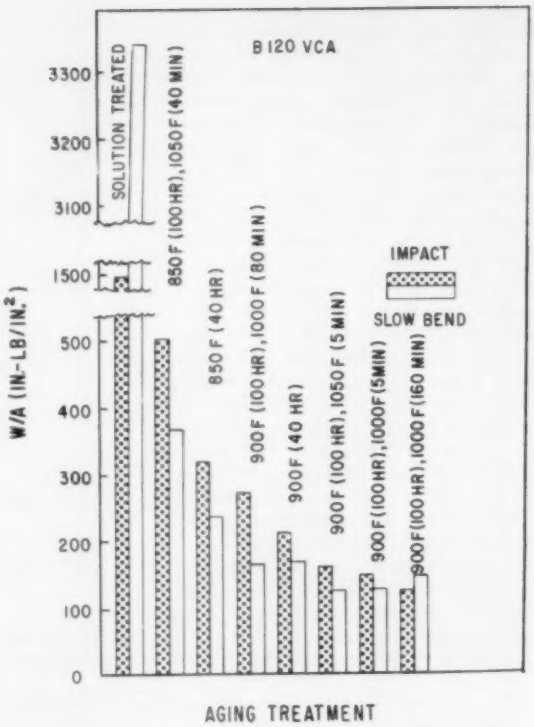


Fig. 18—Impact and slow-bend fatigue-cracked V-notch Charpy tests of B120VCA titanium after various heat treatments. Note the marked strain-rate sensitivity in the solution-treated condition. The figures above each set of bars represent the aging and flash annealing treatments given at Armour Research Foundation

for two tests in slow-bend and three in impact. The rate of head movement in slow bend was 0.05 in./min. The velocity of the pendulum was 11.3 ft/sec in impact testing. Precracking was accomplished by fatiguing the V-notched Charpy specimens. In the lefthand plot of Fig. 16, energy per unit of crack area (W/A) is used as a criterion for fracture toughness. Note that all the sheet alloys tested exhibited greater fracture toughness in impact than in slow-bend. The differences in fracture toughness between impact and slow-bend are large enough to be of practical significance, yet small enough to suggest that they may be merely the result of energy losses in impact testing that were not present in the slow-bend tests. To determine whether the differences in fracture toughness between slow bend and impact were real, lateral expansion measurements* were taken at the compression faces of the broken Charpy specimens (right-hand plot of Fig. 16). Note that with lateral expansion as the criterion, without exception the impacted specimens exhibited the greater toughness. Furthermore, proportionately, the differences in fracture toughness between impact and slow-bend are essentially the same with both criteria, except where the lateral expansion values were too low for accurate measurement. Thus, since lateral expansion is independent of energy losses, the differences in energy to fracture between slow-bend and impact are real.

Figure 17 represents fracture toughness data from impact and slow-bend tests in several sheet-steel materials heat treated to various strength levels. The slow-bend data represent the results from a single test and the impact data represent averages from two or more tests. Head speed in the slow-bend tests was approximately 0.75 in/min. Note that with only two exceptions, fracture toughness values in impact ran higher than those in slow-bend. The figures above each bar on the graph represent (*a*) the percentage of shear-lip (45 deg fracture) measured at mid-depth on the specimens where it attains its maximum value, (*b*) the type of steel and (*c*) the 0.2% offset yield strength. Note that with but one exception the higher percentage of shear lip is associated with the higher fracture-toughness value.

The data in Fig. 18 were obtained from a single heat of B120VCA titanium sheet, heat treated to various strength levels. Both the impact and the slow-bend Charpy tests were run in duplicate.† Once again higher fracture-toughness values were indicated for the specimens broken in impact, with but two exceptions. In the solution-treated condition, the W/A value for slow-bend is more than twice that observed in impact and was accompanied by a major change in

* The lateral expansion measurement has been shown to be a highly significant measurement in conventional Charpy testing of constructional steel plate materials, bearing a direct relationship to absorbed energy.[5] In high-strength steel and titanium sheet materials, the lateral expansion measurement is not usually a useful criterion because of the very low values encountered, the deformation caused by the tup, and the jagged nature of the break on the compression face of the specimens. However, lateral expansion in precracked specimens of the tougher grades of aluminum sheet alloys is not seriously affected by these factors. A comparison between lateral expansion and W/A indicates that lateral expansion in the aluminum sheet alloy specimens is closely related to energy to fracture except in the more brittle materials. In the brittle materials,

fracture appearance; i.e., the impacted specimens exhibited a 100% oblique shear fracture; whereas, in slow-bend the fracture was of a flat type observed in other very ductile titanium alloys in the annealed condition. The pronounced loss of fracture toughness in impact for annealed B120VCA has been observed in other B120VCA heats.

Notch/Unnotch Tensile Ratio

Corrigan[10] has conducted tests of high-strength sheet materials using sharp notched tensile specimens conforming to the recommendations of the ASTM Committee on Fracture Testing of High-Strength Sheet Materials. V-notch Charpy specimens were cut from Corrigan's broken tensile specimens in four titanium alloys in a variety of heat-treated conditions. The specimens were precracked by fatigue and tested in impact at room temperature. The results are presented in Table 5 and Fig. 19. Note that as the notch/unnotch tensile-strength ratio approached unity, the slope of the curve increased rapidly, indicating that as the toughness increased the notched tensile test lost its ability to distinguish between different materials. The scatter at the lower end of the curve may be due to the difficulty of machining sufficiently sharp notches in heat-treated tensile specimens. Consider for example the plotted point showing the lowest W/A value and which also falls farthest from the curve. In the smooth tensile test this material broke with 0% elongation; therefore, this is an extremely brittle material (as indicated by the Charpy test but not by the notch/unnotch tensile ratio). The plotted point showing the maximum notch/unnotch tensile strength ratio also falls well off the curve. The material represented by this point is annealed B120VCA which has been shown to be highly strain-rate sensitive. Based on previous experience with B120VCA in the annealed condition (Fig. 18), it is anticipated that had the W/A value been obtained in slow-bend (to approximate the strain rate prevailing in the tensile test), the value would have been approximately doubled and the plotted point would have fallen close to the projected curve.

Summary and Conclusions

This investigation, using a wide variety of sheet alloys, has demonstrated that the precracked Charpy specimen provides an economical, sensitive, reproducible and meaningful test which permits easy evaluation over a wide range of tem-

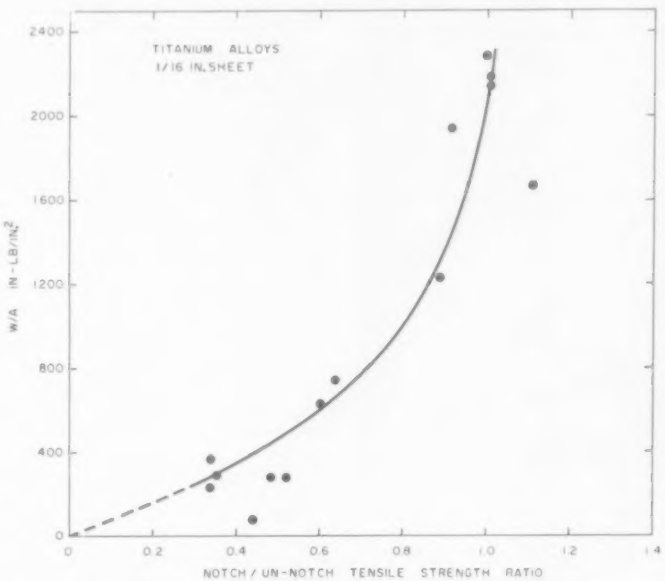


Fig. 19—Relationship between notch/unnotch tensile-strength ratio and fatigue-cracked V-notch Charpy impact W/A

Table 5—Charpy W/A vs. Notch/Unnotch Tensile Strength Ratio

Material	Heat treatment	Unnotched tensile, ksi	Elongation, %	Notch/unnotch tensile ratio[a]	Impact W/A[a] in-lb/in.²
Ti-140A	1600° (1/4 hr) AC	168.4	...	0.34	220
Ti-140A	1300° (1 hr) WQ	138.9	16.5	1.004	2185
Ti-140A	1300° (1 hr) WQ 800° (2 hr) AC	184.1	1.0	0.35	354
Ti-140A	1350° (1 hr) WQ 800° (1 hr) AC	175.7	4.0	0.64	736
Ti-140A	1350° (1 hr) WQ 1100° (24 hr) AC	125.7	21.0	1.001	2290
Ti-140A	1480° (1/4 hr) AC 900° (2 hr) AC	157.0	9.0	0.89	1224
Ti-155A	1650° (1/4 hr) AC 900° (7 hr) AC	176.3	0	0.44	78
B-120VCA	As-received	131.0	22.0	1.11	1668
B-120VCA	900° (20 hr) AC	173.4	9.0	0.60	615
B-120VCA	900° (100 hr) AC	203.5	6.0	0.35	281
4Al-3V-1Mo	1400° (1 hr) WQ	127.6	11.5	1.01	2150
4Al-3V-1Mo	1500° (1/4 hr) AC	131.5	13.0	0.92	1932
4Al-3V-1Mo	1650° (1/4 hr) WQ 900° (2 hr) AC	201.8	4.5	0.52	288
4Al-3V-1Mo	1650° (1/4 hr) WQ 700° (7 hr) AC	201.0	4.0	0.48	289

[a] Averages of two values.

the relationship is upset by elastic-energy effects which are recorded as energy absorbed but do not result in plastic expansion of the specimen.

† It was concluded from these and other precracked Charpy tests[9] that the room temperature fracture toughness of all-beta B120VCA is quite low in the aged condition. Dr. Irwin has suggested that sheet for rocket motor casings should have sufficient toughness to withstand a "2t" crack length at yield strength stresses. This criterion calls for a minimum G_c of approx. 650 in lb/in.² in titanium at a yield stress of 175 ksi. When the B120VCA was solution treated and aged to 175 ksi (strength/weight ratio of 1,000,000), the W/A values were less than 300 in-lb./in.². The transition from high to low fracture toughness in the aged material occurred at or above room temperature in all cases.

perature and at widely different rates of loading.

Precracking is accomplished by means of a fatigue machine which can be made to shut off automatically when the crack reaches a predetermined depth (after fatigue cycling for about 2 min). The as-received or as-heat-treated surfaces of the sheet are not removed; i.e., only the edges of the testpiece are machined. Furthermore, the specimen requires less than 1 sq in. of sheet, as opposed to 18–26 sq in. for most fracture-toughness tensile tests. Thus, because of the economy of material, machining and testing, the precracked Charpy permits screening of a large number of sheets, heats or metallurgical variables at nominal cost.

Comparisons between the precracked Charpy and various fracture-toughness tensile tests indicate that the Charpy results not only provide significant qualitative trends but also a linear and near one-to-one relationship with G_c centrally notched tensile test results.

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Welding Research Council Moving into New Office

The Welding Research Council is moving over the Labor Day week end to a new United Engineering Center at United Nations Plaza (345 E. 47th St., New York 17, N. Y.). The United Engineering Trustees, Inc., owner and operator of the $12,000,000 building which will house nineteen professional engineering organizations, will dedicate the new building late in October, although actual occupancy will take place in early September. Former President Herbert Hoover will serve as honorary Chairman of the dedication ceremonies of the new twenty-story United Engineering Center, which is believed to be the largest assembly of professional engineering organizations in the free world.

United Engineering Trustees, Inc., consists of five Founder Societies: American Society of Civil Engineers, American Society of Mechanical Engineers, American Institute of Mining, Metallurgical and Petroleum Engineers, American Institute of Electrical Engineers, and American Institute of Chemical Engineers. These engineering societies comprise some of the sponsors of the Welding Research Council.

All subscribers, research workers, committee members and members of the Main Council of WRC are cordially invited to visit the new offices while they are in New York City. We will look forward to seeing you and discussing our research activities with you.

K. H. KOOPMAN
Director

Welding Nodular Iron Without Post-Weld Annealing

Satisfactory results are obtained with a combination of "buttering" and welding when using ENiFe rod for overlay deposits and a modified ERN69 rod for final welding

BY R. C. BATES AND F. J. MORLEY, JR.

ABSTRACT. Strong, crack-free welds can be readily made in nodular iron castings using ENiFe electrodes with minimum preheat and interpass temperatures of 600° F. However, if arc welding is used, a layer of extremely brittle massive carbide is formed in the fusion lines. This is caused by the rapid solidification of the small pool of molten metal formed by melting a portion of the base and filler metals. As a result, the impact strength and ductility are poor. A post-weld, graphitizing-ferritizing anneal will decompose the carbide so that good ductility and impact properties are obtained, but welding is frequently performed in the field where annealing facilities are not available. Thus, a welding process is needed that will produce ductile joints without a post-weld heat treatment if nodular cast iron is to achieve its maximum usage.

The necessity of post-weld annealing is eliminated with a technique involving the deposition of weld overlays on surfaces of nodular iron castings which are to be subsequently joined. Overlays are obtained by depositing a series of small "stringer-bead" layers. This operation (frequently called "buttering") can be performed at the foundry prior to the annealing treatment normally required in the production of ferritic nodular cast iron. Since the subsequent final welding operations performed in the field affect only the overlay deposits, no massive carbide is formed in the fusion lines and no post-weld heat treatment is required.

If the proper combination of electrodes is used, the ductility of joints welded with the overlay technique (with no post-weld heat treatment) is far superior to the ductility of as-welded joints made without an overlay deposit. In fact, it is equivalent to the ductility of fully annealed weldments in nodular iron castings. Satisfactory ductility was obtained with either E307-15 or E6016 electrodes for both the overlay deposits and final welding modified ERN69 (67 Ni, 15 Cr, 8 Fe, 7 Mn, 2 Cb, 1 Ti) for the final welding.

Joints welded with E307-14 for both the overlay deposit and the final welding exhibit excellent room temperature Charpy V-notch impact and V-notch drop weight impact properties. The ductile-to-brittle transition temperature of these joints is higher than that of the base metal, but the nil-ductility transition temperature is still sufficiently low as to preclude the possibility of brittle (cleavage) failure if the service temperature is at or above room temperature. Similar results are obtained if ENiFe electrodes are used for the overlay deposit and modified ERN69 electrodes are used for the final welding. The nil ductility transition temperature of joints utilizing E6016 for both the overlay deposit and final welding is above room temperature.

The proper selection of electrodes is vital if satisfactory results are to be obtained. Of the welding rods evaluated, only the modified ERN69 produced sound ductile joints when ENiFe was used for the overlay deposits. ENiFe, ENi, E6016 and E307-15 were also investigated for final welding in conjunction with ENiFe overlay deposits, but excessive porosity in the overlay metal-weld metal junction was encountered when these rods were used. This porosity caused poor ductility even though no massive carbide was present in the welds, base metal or fusion lines. No significant porosity was encountered when either E307-15 or E6016 were used for both the overlay deposit and final welding.

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Paper to be presented at the AWS National Fall Meeting in Dallas, Texas, during Sept. 25–28, 1961.

Introduction

Nodular cast iron, in its most commonly used form, consists of spherical graphite particles embedded in a matrix of ferrite as shown in Fig. 1. The characteristic, spherical shape of the graphite particles is normally achieved by innoculation of the liquid metal with magnesium. Although the matrix, in the as-cast condition, is usually pearlite or partially pearlite, a ferritic matrix is obtained with a graphitizing-ferritizing annealing treatment performed at the foundry. Typical properties of annealed, ferritic nodular iron are 55–65,000 psi ultimate strength, 45–55,000 psi yield strength (0.2% offset) and 15–20% elongation.

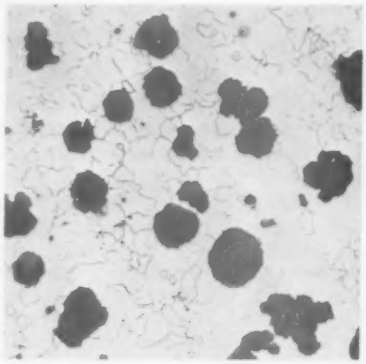

Fig. 1—Typical area in a ferritic nodular cast iron sample as annealed. Etchant 2% Nital. × 250. (Reduced 40% on reproduction)

Crack-free arc welds can readily be made in nodular iron castings using ENiFe welding rods with minimum preheat and interpass temperatures of 600° F; however, the normal ferrite-graphite microstructure is not retained. In arc welding, the small pool of molten metal, formed by melting a portion of the base and filler metals, freezes so rapidly that a layer of extremely brittle massive carbide is formed at the base metal-weld metal junction lines as shown in Fig. 2. Although the strength of such weldments is equivalent to or higher than that of the unwelded nodular iron, the ductility is generally very poor, especially across the carbide layers at the junction lines.

A post-weld, graphitizing-ferritizing anneal will decompose the carbides so that good ductility and impact properties are obtained, but frequently welding is performed in the field where annealing facilities are not available. Thus, if nodular cast iron is to achieve its maximum usage, a welding process is needed that will produce ductile joints without post-weld heat treatment.

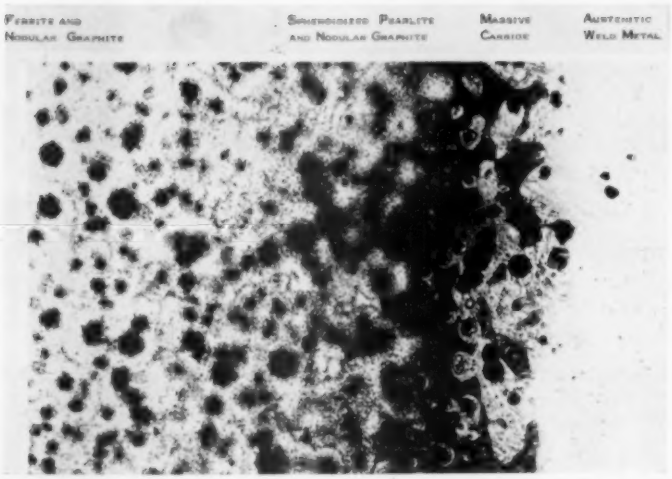

Fig. 2—View of nodular iron-ENiFe arc welded joint in as-welded condition. Etchant 2% Nital. × 100. (Reduced 50% on reproduction)

In order to obtain ductile welds in nodular iron without post-weld annealing, a technique was investigated involving the deposition of weld overlays on the surfaces of nodular iron castings that are to be subsequently joined. This operation (frequently called "buttering") can be performed at the foundry prior to the graphitizing-ferritizing anneal required in the production of ferritic nodular cast iron. Deleterious carbides formed during the deposition of the overlay deposits are eliminated by the foundry anneal. Subsequent welding operations performed in the field affect only the overlay deposits which are not susceptible to the formation of massive carbide during welding, thus eliminating the need for post-weld annealing.

The investigation entailed an evaluation of several welding rods for both buttering and final welding. Evaluations of the microstructures, tensile properties, bend ductility and impact properties of joints made with the buttering-welding technique were included.

Preparation of Specimens

Several nodular iron plates (dimensions $^{7}/_{8}$ x $5^{1}/_{2}$ x 14 in.) were cast in dry sand molds from an electric furnace heat of the following composition: C, 3.68%; Si, 2.23%; P, 0.041%; Mg, 0.06%; Ni, 0.70%; Mn, 0.44%; and Fe, remainder.

The plates were given an annealing treatment consisting of: (*a*) heating for 4 hr at 1650° F, (*b*) furnace cooling at 60° F per hr to 1000° F, (*c*) cooling in air to room temperature.

Several of the plates were set aside for later use as unwelded control specimens. Others were sectioned in preparation for welding so that two half-plates (dimensions $^{7}/_{8}$ x $5^{1}/_{2}$ x 7 in.) were obtained from each; one of the $5^{1}/_{2}$ in. sides of each was then machined to a 30 deg bevel.

Welding Procedure

ENiFe, E307-15 and E6016 welding rods were evaluated for buttering. In each case immediately after furnace preheating the nodular iron samples, stringer beads were deposited on the beveled ends, as shown in Fig. 3, to provide a $^{1}/_{4}$ to $^{3}/_{8}$ in. overlay. The preheat temperature used on samples buttered with ENiFe and E6016 was 600° F, and the interpass temperature was maintained at 550–600° F. The preheat and interpass temperatures used for depositing the E307-15 overlay were 800° F and 650–700° F, respectively.

Prior to final welding, the buttered plates were given a graphitizing-ferritizing anneal similar to that previously described. The buttered faces were then machined to provide smooth, clean surfaces having a 30 deg. bevel for final welding.

The buttered plates were paired, and each pair was placed in a holding fixture as shown in Fig. 4. The fixture was designed to restrain the plates so they formed a 60 deg. single vee with a $^{1}/_{8}$ in. root opening. A thin strip of nodular iron was used as a back-up bar at the root opening.

The complete assembly of plates and fixture was preheated in a furnace prior to welding. A preheat temperature of 600° F was used for all samples except those welded with E307-15. The latter were preheated to 800° F.

The same types of welding rods as those used for buttering were evaluated for final welding. In addition ENi and modified ERN69 electrodes were also tried for welding several samples buttered with ENiFe. The composition of modified ERN69 is: Ni, 67%; Cr, 15%; Fe, 8%; Mn, 7%; Cb, 2%; and Ti, 1%.

Approximately 20 passes were required to weld each pair of test plates. The root and initial passes were made with $^{1}/_{8}$-in. diam electrodes, and $^{5}/_{32}$ in. diam electrodes were used for the final weld passes.

Test Procedure and Results

Metallographic Examination

A thin slice was cut from each buttered nodular iron sample for metallographic examination prior to annealing. Similar strips were cut after heat treatment but prior to final welding, and additional strips were cut from the samples after final welding.

A typical nodular iron base metal-ENiFe overlay metal deposit is

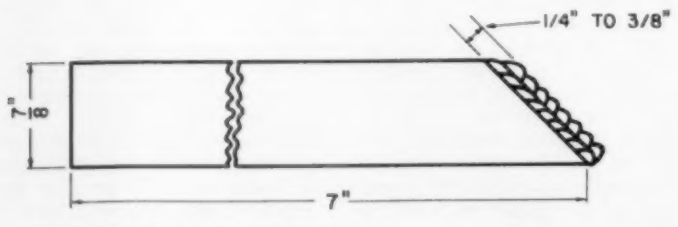

Fig. 3—Weld overlay on nodular iron

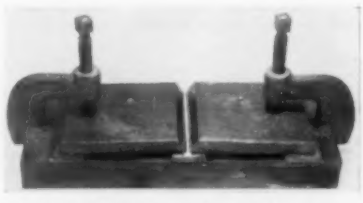

Fig. 4—Holding fixture for welding nodular iron plates

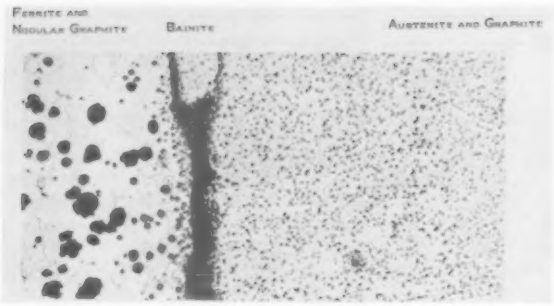

Fig. 5—Junction of nodular iron base metal and ENiFe overlay metal. Etchant 2% Nital. × 100. (Reduced 45% on reproduction)

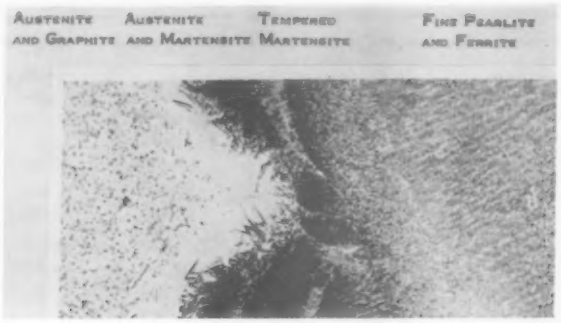

Fig. 6—Junction of ENiFe overlay metal and E6016 weld metal. Etchant 2% Nital. × 100. (Reduced 35% on reproduction)

shown in Fig. 5. In this particular joint, ENiFe was used for the final weld (not shown in Fig. 5), but the same type of microstructure was obtained in the base metal-ENiFe overlay deposit regardless of the type of welding rod used for the final weld. The microstructure of the base metal is similar to that of unwelded, annealed nodular iron. The numerous small graphite particles in the base metal immediately adjacent to the junction line resulted from the decomposition of massive carbides during the intermediate anneal. The overlay metal contains a thin layer of lower bainite ranging in thickness from 0.0005 to 0.002 in. adjacent to the junction line. At greater distances from the junction line, the microstructure is typical of ENiFe deposits and consists of graphite embedded in a matrix of austenite.

No transformation products such as carbide, martensite or bainite are present in the junction between the ENiFe overlay deposit and the ENiFe weld deposit. The only discernible difference in the microstructure of these deposits is a change in the orientation of the graphite particles which are typically embedded in the austenitic matrix. For this reason, no photograph is shown of the ENiFe overlay-ENiFe weld junction.

Fig. 6 is a view of a typical section of an ENiFe overlay metal-E6016 weld metal junction. A layer of tempered martensite is present in the E6016 weld metal adjacent to the junction line, and the remaining portion of the weld is composed of a mixture of fine pearlite and ferrite.

A typical junction of ENiFe overlay metal and modified ERN69 weld metal is shown in Fig. 7. No transformation products whatever are contained in the junctions or adjacent areas. Similar results were obtained in joints utilizing ENiFe for the overlay deposit and E307-15 for the final weld.

A view of the base metal-E6016 overlay metal junction is shown in Fig. 8. Again, no massive carbide is present, and the base metal is similar to the structure normally found in annealed nodular iron. The structure of the overlay deposit near the junction consists of coarse lamellar pearlite with excess carbides and a few large nodular graphite particles. Away from the junction line, a mixture of fine pearlite and ferrite is found. At greater distances, the amount of pearlite gradually diminishes until near the center of the final weld (not shown) only about 5–10% pearlite is present.

The base metal of the samples buttered and welded with E307-15 (Fig. 9) is similar to that of the previously described welds, i.e., graphite nodules embedded in a ferrite matrix. Again, no massive carbide whatever was found in the weld zone. A mixture of pearlite, ferrite and excess carbide appears as a thin layer in the overlay metal adjacent to the junction line. A thin layer of tempered martensite and excess carbide is found next, and a mixture of austenite and excess carbides forms the remaining portion of the overlay deposit and final weld. As in the samples buttered and welded with ENiFe, no clearly discernible junction line is present between the E307-15 overlay metal and E307-15 final weld so no photograph of this junction is shown.

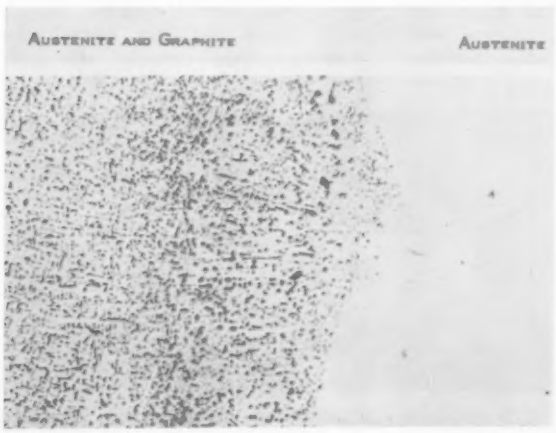

Fig. 7—Junction of ENiFe overlay metal and modified ERM 60 weld metal. Etchant 9% Nital. × 100. (Reduced 30% on reproduction)

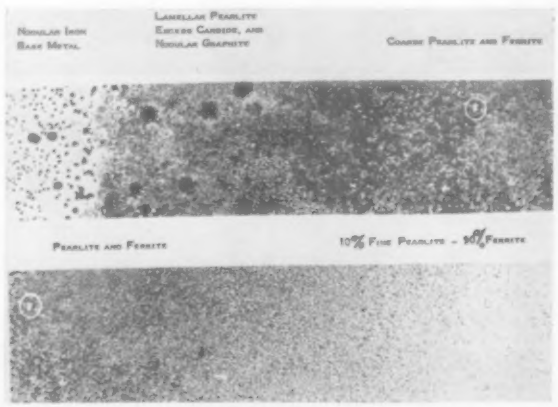
Nodular Iron Base Metal
Lamellar Pearlite Excess Carbide, and Nodular Graphite
Coarse Pearlite and Ferrite
Pearlite and Ferrite
10% Fine Pearlite - 90% Ferrite

Fig. 8—View of nodular iron base metal and E6016 overlay metal. Etchant 2% Nital. × 100. (Reduced 55% on reproduction)

Table 1—Mechanical Properties of Unwelded and Welded Nodular Iron[a]

Rod used for overlay	Rod used for welding	Post weld anneal	Tensile strength, psi	0.2% offset yield strength, psi	Elongation, %	Bend angle in root bend test, deg
Unwelded			61,500	48,000	19.0	30
...	ENiFe	No	65,000	57,000	1.0	2
...	ENiFe	Yes	60,500	44,000	10.0	14
ENiFe	ENiFe	No	56,300	44,500	2.6	2
ENiFe	ENi	No	53,800	47,800	3.2	5
ENiFe	Modified ERN69	No	64,000	44,800	10.6	12
ENiFe	E307-15	No	...	...	...	2
ENiFe	E6016	No	...	...	...	3
E307-15	E307-15	No	60,200	43,700	6.7	20
E6016	E6016	No	61,600	44,300	5.2	12

[a] Each value represents the average of two tests.

Table 2—Results of Drop Weight Tests

Temperature, °F	Unwelded nodular iron	Buttered and welded with E307-15	Buttered with ENiFe welded with modified ERN69
50	...	OO	OO
35	...	O[a]	X
25	...	X[b]	X
0	O	X	X
−25	O	...	...
−35	X	...	...
−50	XX	...	...

[a] O indicates specimen did not break during test.
[b] X indicates specimen broke during test.

Tensile Tests

Tensile tests were performed on specimens machined from several samples buttered and final welded with various combinations of electrodes. Table 1 contains a comparison of the tensile properties of these specimens with the properties of unwelded control samples and conventionally arc welded nodular iron samples (both as-welded and annealed).

The yield and tensile strengths of all of the welded joints are comparable to those of unwelded nodular cast iron. The tensile ductility of samples buttered and welded with ENiFe rods is only slightly higher than that of conventionally arc welded samples in the as-welded condition. Similar results were obtained on specimens buttered with ENiFe and final welded with ENi. However, the specimens buttered with ENiFe and final welded with modified ERN69 rods exhibited excellent tensile ductility. In addition, good tensile ductility was found for specimens buttered and welded with E307-15 rods and specimens buttered and welded with E6016 rods.

Slow Bend Tests

Several specimens were machined to provide bend test specimens (dimensions $^5/_8$ x $3^1/_2$ x 14 in.). Root bend tests were made using a $1^1/_4$-in. diam mandrel and a $5^1/_2$ in. loading span. The bend tests were stopped immediately upon the initiation of cracks; the bend angles were then measured and are recorded in Table 1.

The bend angles of samples buttered and welded with ENiFe, like conventionally arc-welded samples in the as-welded condition are extremely low despite the elimination of massive carbide from the fusion lines. In these samples, considerable amounts of porosity were present in the secondary fusion lines (junctions of the overlay deposit and the final welds) which caused failures without appreciable bending. Similar results were obtained with samples buttered with ENiFe and final welded with E30715 E6016 or ENi welding rods. The porosity problem was not encountered in the samples buttered and welded with E307-15 and E6016, and in those buttered with ENiFe and welded with modified ERN69. Large bends were obtained during the slow bend tests of these samples.

Prior to bend testing, lines were scribed at $^1/_8$ in. intervals across the weld zones and adjacent weld metal as shown in Fig. 10. Measurements of the interval elongations which occurred during the bend tests permit a comparison of the relative ductilities of each zone in the welds.

In the samples conventionally arc welded with ENiFe without post-weld annealing, the bending is completely restricted to the weld metal as shown in Fig. 11. On the other hand, bending is not restricted to the weld metal in the annealed samples.

The samples buttered and welded with E307-15 and with E6016, and the ENiFe-modified ERN69 samples also exhibit good ductility in the increments containing the junction lines as well as in the weld metal and base metal. This is shown in Fig. 12. The other buttered and welded samples exhibit only slight ductility across the junction lines due to the pre-

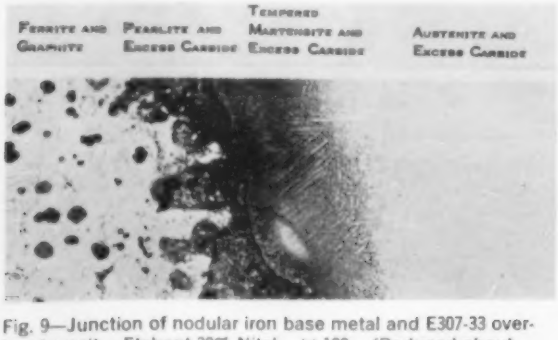
Ferrite and Graphite
Pearlite and Excess Carbide
Tempered Martensite and Excess Carbide
Austenite and Excess Carbide

Fig. 9—Junction of nodular iron base metal and E307-33 overlay deposit. Etchant 20% Nital. × 100. (Reduced about 40% on reproduction)

Fig. 10—Slow bend tested nodular iron specimen which was annealed after welding. (Note: Root of weld was in tension during bending. Increments marked off before testing allowed measurements of relative ductility of each zone across weld and heat-affected area)

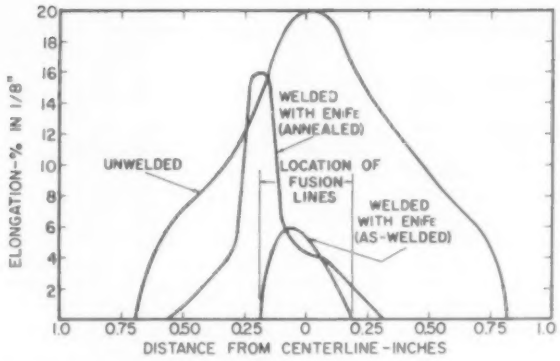

Fig. 11—Elongation during slow root bend tests of $^1/_8$ in. increments across weld zone in unwelded and arc-welded nodular iron

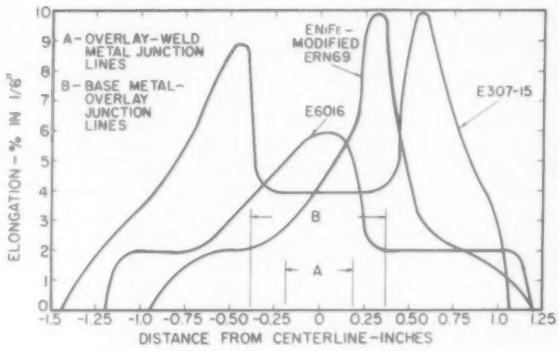

Fig. 12—Elongation of $^1/_8$ in. increments across weld zone during root bend tests of buttered and welded samples

viously mentioned junction line porosity.

Impact Tests

The impact energy absorbed by unwelded, annealed, nodular iron Charpy V-notch specimens at temperatures in the range −100 to 125° F is shown in Fig. 13. In addition the nil-ductility transition temperature of this material was determined by testing of drop weight specimens as −35° F. The actual drop weight data are recorded in Table 2. The dimensions of the drop weight specimens used to determine the transition temperature were $^5/_8$ x 2 x 5 in. Instead of using a notched brittle weld bead deposit, such as is normally used on drop weight specimens, a notch was machined across the entire 2 in. width of each specimen to a depth of 0.080 in. at an angle of 45 deg. The radius at the bottom of the notch was 0.010 in.

Charpy V-notch specimens were also machined from samples buttered and welded with the three combinations of electrodes which exhibited the highest slow bend and tensile ductilities. These combinations of electrodes were ENiFe-modified ERN69, E307-15 for both buttering and welding, and E6016 for both buttering and welding. In each case, the specimens were notched in such a manner that the fracture would propagate across equal portions of the base metal and overlay deposit. As shown in Fig. 13, the impact properties of the ENiFe-modified ERN69 and the E307-15 samples, while not as good as unwelded nodular iron, were satisfactory. Drop weight specimens were tested to further evaluate these welds; test results are shown in Table 2. These specimens were similar to the unwelded nodular iron drop weight specimens previously described; however, the notches were placed at the base metal-overlay junctions so that the fracture, once initiated, could propagate through the overlay metal, base metal or junction line—whichever was the weakest path. The nil-ductility transition temperatures determined for the ENiFe-modified ERN69 samples and the E307-15 samples were 35 and 25° F respectively. Drop weight specimens were not prepared from the samples buttered and welded with E6016 because of the extremely low energy absorbed by Charpy V-notch specimens from this material at all temperatures below 150° F.

Metallographic examination of E307-15 broken drop weight specimens revealed that the fractures had propagated primarily through the martensitic layer near the base metal-overlay metal junction. The fractures in the ENiFe-modified ERN69 specimens had propagated primarily through the bainitic layer adjacent to the junction lines in the ENiFe overlay metal.

Discussion

Metallographic examination revealed that no massive carbide was present in any of the joints made with the buttering-welding technique even though these samples received no post-weld heat treatment. It is evident, therefore, that this technique can be used in fabrications without a post-weld annealing treatment without fear of forming deleterious carbide layers in the fusion lines. It is necessary, however, to select the proper combinations of welding rods for the buttering and final welding operations if optimum properties are to be obtained. The combinations of welding rods for buttering and final welding that provide good slow bend and tensile ductilities are:

1. ENiFe electrodes for buttering and modified ERN69 elec-

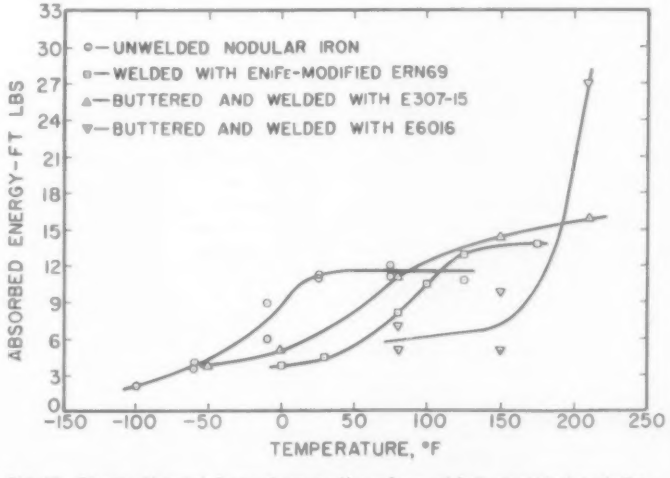

Fig. 13—Charpy V-notch impact properties of unwelded annealed nodular iron and nodular iron welded with an overlay deposited prior to welding

trodes for final welding.
2. E307-15 rods for both buttering and welding.
3. E6016 electrodes for both buttering and welding.

The ductilities of specimens produced by any of these combinations without post-weld heat treatment are far superior to the ductility of conventional arc-welded samples not given a post-weld annealing treatment. Furthermore, since no massive carbide layer is formed, samples prepared by the buttering-welding technique do not contain brittle zones. In this respect, they are similar to conventionally arc welded samples that are fully annealed after welding.

Although the transition temperature of the ENiFe-modified ERN69 welds was measured as 10° F higher than that of the E307-15 welds, this is not considered significant since 10° F is less than the accuracy of the test. Both combinations of buttering and welding electrodes produce joints that exhibit sufficiently low transition temperatures to preclude the possibility of brittle fracture at temperatures at or above room temperature. Thus, in view of the excellent combination of strength, tensile ductility, slow bend ductility and impact properties, these two combinations can be safely used for the majority of room temperature applications requiring welding of nodular iron castings during fabrication.

The choice between ENiFe, modified ERN69, or E307-15 electrodes for the buttering operation may ultimately depend on whether the nodular iron casting is being joined to another nodular iron casting or to a dissimilar metal. Normally, ENiFe is used for welding nodular iron. Thus, it may be desirable to use the ENiFe-modified ERN69 combination when welding nodular iron to itself or carbon steel. If, on the other hand, nodular iron is being joined to stainless steel, a stainless steel electrode would be the logical choice for both buttering and final welding. If transition temperature is of no importance, E6016 should be considered for both buttering and welding.

The poor ductility of the welded joints made by buttering with ENiFe electrodes and then welding with an electrode other than modified ERN69 alloy is undoubtedly due to the excessive porosity in the overlay metal-weld metal junction. In all cases, the overlay metal-base metal junction is sound and free of massive carbide.

Conclusion

The ductility of welded joints in nodular iron made with either E307-15 for both buttering and final welding or with ENiFe for buttering and modified ERN69 rods for final welding (with no post-weld heat treatment) is far superior to the ductility of as-welded joints made without buttering, and in fact, is equivalent to annealed weldments in nodular iron casting.

No post-weld heat treatment of joints made with the buttering-welding technique is required; however, the buttering operation must be performed prior to the graphitizing-ferritizing annealing treatment given at the foundry, or a similar heat treatment must be given prior to final welding.

The nil-ductility transition temperature of joints produced by the buttering-welding technique using ENiFe for buttering and modified ERN69 for welding or E307-15 for both buttering and welding is sufficiently low as to preclude the possibility of brittle fracture at service temperatures at or above room temperature.

Acknowledgments

The authors wish to thank J. W. Kehoe of Westinghouse Metals Joining Laboratories and J. Heuschkel of Westinghouse Research Laboratories for their helpful discussions on the overlay technique and the selection of electrodes for this investigation.

EUROPEAN WELDING RESEARCH

(Continued from page 392-s)

• Tensile specimens were cut from top and bottom of butt welds made with $^{3}/_{16}$-in. austenitic electrodes (22Cr – 15Ni) in ferritic Cr-Ni-Mo plate 2 in. thick. The specimens pulled transverse to the weld had lower ductility than the longitudinal specimens. A long arc caused lower ductility than a short arc, particularly in specimens cut from the top of the joint. This was attributed to the high nitrogen content, 0.15%, of the joint made with long arc, compared with 0.027% nitrogen in the short-arc weld. No cracks were detected.

• An electron-beam welder for reactive metals is described. The tank is 10 ft long, 4 ft in diam and operates at 20,000 v.

• The electroslag welding of blast furnace stoves $^{1}/_{2}$ in. thick is described.

• A machine is described for submerged-arc welding of two joints simultaneously.

WEST GERMANY

Stahl und Eisen for Oct. 27, 1960 contains a paper originally delivered in 1958 describing impact, bead bend and Navy tear tests on 37 mild steels in $^{3}/_{8}$, $^{3}/_{4}$, 1 and $1^{9}/_{16}$ in. thicknesses. The sharp notch impact tests provided the most worthwhile results. The weld-bead bend and Navy tear tests responded too greatly to plate thickness. The most significant result was the close correlation of transition temperature of aged normalized steels with the factor % P + 5% N – % Al factor seemed to explain the superiority of open hearth over Bessemer steels, of fine-grain over coarse-grain and of killed and semikilled over unkilled steels.

Abrasion Tests

The West German magazine *Schweissen und Schneiden* for November 1960 discusses two types of abrasion tests made on hard surfacing materials. In one test a revolving cylindrical specimen that had been hard surfaced was rotated in a sand bath at room temperature, 480 and 1110° F. In the other test a blast of sand or coke was directed at angles from 0 to 90 deg on the surface that had been hardsurfaced. Low-alloy steel deposits exhibited the highest wear; high-carbon, high-chromium deposits were intermediate, while tungsten carbide deposits were most wear-resistant. In the sandblast, all materials except the tungsten carbide type were less resistant than mild steel. In a coke blast, all were more resistant than mild steel.

Superalloy Multilayer Sandwich Structures for Application to 1800° F

A satisfactory technique is developed for fabricating Inconel "X" and René 41 multilayer sandwich structures using vacuum furnace brazing and commercial brazing alloys

BY H. SMALLEN

ABSTRACT. This program was part of an over-all maneuverable satellite study to develop a suitable technique for fabricating a space cabin structure capable of withstanding service temperatures for the operating time associated with re-entry into the earth's atmosphere. Inconel "X" and René 41 were selected for services up to 1500 and 1800° F respectively. A sandwich construction was considered to provide the highest strength to weight structure.

The brazed structure in this investigation was required to withstand exposure to either 1500 or 1800° F for times associated with a space vehicle re-entry into the earth's atmosphere. Only commercially available brazing alloys were chosen for evaluation because of the limited time required to complete the over-all program. Nickel-base, semiprecious and precious metal base brazing alloys were selected for final evaluation. Part of the investigation concerned the proper selection of the heat treatment to obtain optimum mechanical properties.

The amount of deterioration of the base metal due to the brazing alloy was determined by brazing on one side of a tensile specimen and then subjecting the specimens to heat treatment and subsequent exposure at the service temperature contemplated. Limited mechanical properties were obtained on the strengths of the superalloys subjected to a simulated braze and heat-treatment cycle and exposure at 1500 or 1800° F for periods of 1 and 5 mm. Base metal tensile ultimate and yield strengths were lowered by the effects of the brazing alloy, brazing cycle and exposure; however, significant strength levels were maintained.

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Introduction

This program was part of an over-all maneuverable satellite study to develop a suitable brazing technique for fabricating a space cabin structure capable of withstanding service temperatures in the 1500–1800° F. range for the operating time associated with re-entry into the earth's atmosphere. Inconel "X" (precipitation hardening nickel-base alloy) was selected because of its satisfactory strength up to 1500° F and its moderate cost compared to the high cobalt alloys. René 41 (also a precipitation-hardening nickel-base alloy) was selected as an alternate alloy for service up to 1800° F.

A sandwich construction was considered to provide the highest strength to weight structure. The multilayer sandwich selected comprised a corrugated sandwich brazed to a honeycomb core. A single corrugated sandwich and double corrugated sandwiches, one brazed to each side of the honeycomb core were developed. Purpose of the corrugated shells was to minimize damage from micrometeoroids. Furnace brazing techniques utilizing vacuum and argon atmospheres were used in this investigation.

The program as originally outlined comprised the selection of suitable brazing alloys for the superalloys in question and the development of techniques for the fabrication of the multilayer sandwich structures.

Service Requirements

1. The brazed structure in this investigation was required to withstand exposure to either 1500 or 1800° F for times associated with a space vehicle re-entry into the earth's atmosphere. For the purpose of this program, time to maximum temperature and time at maximum temperature were considered to be 5 min each. Lowest operational temperature anticipated was considered to be −60° F.

2. No significant deterioration of the base metal should result from the braze alloy and/or the brazing heat cycle on the exposure cycle.

3. Normal oxidation or other characteristic deterioration of the base metal as a result of the specified thermal exposure was acceptable.

4. The strength of the braze joint should be satisfactory so that adequate base metal strength could be achieved throughout the temperature range to 1500 or 1800° F.

Table 1—Chemical Composition of Superalloys

	Inconel "X"	Rene' 41
C (max)	0.08	0.12
Mn (max)	1.00	0.10
Si (max)	0.5	0.50
Al	0.50–1.00	1.40–1.60
Ti	2.25–2.75	3.00–3.30
Mo	...	9.00–10.50
Cr	14.00–17.00	18.00–20.00
Co	...	10.00–12.00
Fe (max)	5.00–9.00	5.00
Others	0.5 Cu 0.7–1.2 Cb	0.003–0.010 B
Ni	Bal	Bal

Superalloy Selection

Inconel "X"

Inconel "X" is an age-hardenable nickel-chromium alloy (Table I) developed to have high stress to rupture strength and low creep rates under high stress at tempera-

Table 2—Brazing Alloy Data

Alloy designation	Composition	Solidus, ° F	Liquidus, ° F	Recommended brazing range, ° F
A	Cr-Si	1975	2075	2100–2200
B	Cr-Si	1975	2075	2100–2200
C	Cr-Si-Pd	1800	2150	2150–2175
D	Si-B	...	...	2150–2200
E	Ni-Au-Cu	1814	1868	1950–1975
F	Ni-Cr-Au	1785	1900	1900–1950

tures up to 1500° F (after suitable thermal treatment) and to be highly resistant to chemical corrosion and oxidation. The alloy owes its high strength to precipitation hardening which occurs during a 1300 or 1400° F aging treatment. Hardening takes place throughout the entire cross section and results in uniformity of properties from surface to center.

Normal heat treatment requires a solution treatment at 2100° F followed by a high temperature age at 1550° F and a low temperature age at 1300° F. For sheets, however, the recommended treatment is a 1300 or 1400° F aging treatment following the mill anneal. Although an aging treatment of 1300° F. for 20 hr is required, a 1400° F aging treatment for 1 or 2 hr should produce comparable results according to the manufacturer.

René 41

René 41 is a complex nickel-base high temperature alloy containing appreciable quantities of cobalt and molybdenum (Table 1). Titanium and aluminum are the reactive elements responsible for age hardening of the alloy. This alloy is useful up to a temperature of 1800° F. Mechanical properties vary with the solution and aging treatments. Higher solution temperature results in better room temperature ductility and higher rupture strength at elevated temperature. Lower solution temperature gives higher tensile strengths. The two commonly used heat treatments are:

1. Solution treat at 2150° F, air cool, age for 4 hr at 1650° F, air cool.
2. Solution treat at 1950° F, air cool, age for 16 hr at 1400° F, air cool.

Brazing Alloy Selection

Many different brazing alloys were considered for both Inconel "X" and René 41 based upon service requirements and processing parameters. These included nickel base, semi-precious and precious metal alloys. Only commercially available brazing alloys were chosen for evaluation because of the limited time required to complete the over-all program. Cost of the brazing alloy was an important factor in the selection. For this reason any real advantages or precious metals in the brazing alloys were tempered by their high cost.

Nickel-base Brazing Alloys

Alloy A is a chromium-silicon alloy free of boron. Its composition and high melting range will produce less diffusion and erosion at 2150° F brazing temperature than some of the lower melting alloys. Oxidation resistance of the joint is satisfactory beyond 1800° F.

Alloy B is a vacuum melted alloy composed of 8.0% silicon, 15.0% chromium and balance nickel.

Alloy D is a low silicon nickel alloy containing a maximum of 0.9% boron.

Semiprecious Metal Base Brazing Alloy

Alloy C is a nickel-chromium-palladium alloy developed for use where embrittlement by alloys containing silicon and boron is excessive. This alloy possesses intermediate fluidity with virtually no interface brittlement of the base material. Oxidation resistance and strength at elevated temperatures is claimed to be very good.

Precious Metal Base Brazing Alloys

Alloy E is 35% gold, the balance being copper and nickel. It has satisfactory wetting and flow characteristics on nickel alloys. Its narrow melting range makes it suitable for brazing involving slow rates of heating.

Alloy F is 72% gold, the balance being nickel and chromium. It is used for continuous service up to 1500° F. Moderate solution of the base metal results during the brazing process.

Processing Parameters

The brazing of high temperature materials requires a sound understanding of the metallurgical reactions between the braze alloy and the base material. The problems in this program were further complicated by the fact that ultrathin components were required to be brazed. Initially the program called for brazing a 15-mil facing sheet to one side, and a $^{5}/_{32}$-in. resistance welded corrugated sandwich to the other side of a $^{5}/_{8}$-in. thick, $^{1}/_{4}$-in. cell, 2 mil foil honeycomb core. Brazing corrugated sandwiches to both sides of the honeycomb core was subsequently considered for the program. The careful consideration of the below significant processing parameters were required to economically effect a satisfactory brazed joint.

Both Inconel "X" and René 41 contain the reactive elements titanium and aluminum. These elements are so reactive during the brazing cycle that oxides will form under most controlled atmospheric conditions, thus inhibiting the satisfactory flow of the brazing alloy. Previous experience with brazing stainless steel and other superalloy honeycomb structures indicated that only dry argon (dew point −65° F or below) or vacuum (30 microns or less) could be used for brazing these materials.

Several of these variables are interrelated and required consideration in combination with others. One factor discovered from previous work was the effect of certain elements in the brazing alloys on intergranular penetration and its associated brittleness. Boron was known to cause this condition in certain alloys containing the reactive elements titanium and aluminum. Silicon was another element known to contribute to intergranular penetration (but to a lesser extent). Both of these elements have certain primary functions in promoting flowing and wetting of the alloy and cannot be eliminated in certain alloys. An important point for consideration was the effect of diffusion of the parent metal with the brazing alloy to raise its remelt temperature by as much as 200° F, thus permitting brazing to be accomplished at lower temperatures.

Both Inconel "X" and René 41 are solution treated at 1950 or 2150° F and subsequently aged at a lower temperature. These solution treatment temperatures were considered in the selection of the brazing alloys.

The method of heating is very important in that it controls the rate of heating, which has a pronounced effect upon the results

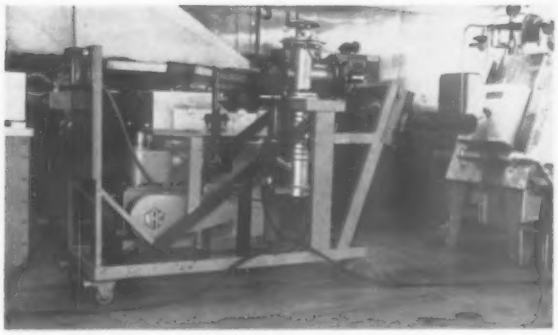

Fig. 1—Furnace brazing equipment

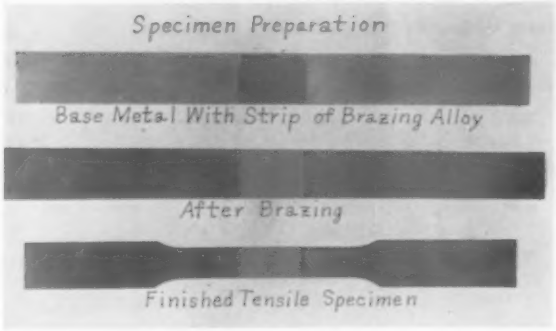

Fig. 2—Preparation of brazed tensile coupon

obtained. A slow rate of heating permits a greater amount of solution of the base metal once the brazing alloys begin to melt. This may be advantageous where a higher remelt temperature is required. Also, certain brazing alloys have a wide solidus—liquidus melting range. On slow heating the lower melting constituents will become molten first leaving behind a higher melting constituent, or skull, which may not melt. This invariably results in a rough surface with poor fillet formation.

Brazing Investigation and Results

Investigation of the processing parameters required to meet the service conditions was conducted using a high temperature furnace as the heat source. Selection of brazing alloys, atmospheres and time-temperature relationships were made based upon service requirements and processing parameters. It was necessary prior to this investigation to determine the most appropriate method of cleaning these superalloys to effect a satisfactory braze.

The methods selected for trial were based upon previous experiences in cleaning other superalloys and stainless steels for honeycomb brazing and upon the recommendations of the superalloy manufacturers. These included an acetone wipe, sodium hydride plus nitric acid dip, and an nitric-hydrofluoric acid cleaning treatment used for PH 15 – 7 Mo stainless steel honeycomb. The nitric-hydrofluoric acid treatment was found satisfactory and was used throughout the program.

The equipment used for furnace brazing in Fig. 1 consisted of an Inconel retort, a high vacuum system (0.2 micron blankoff vacuum), commercial dryer for the argon supply and a specially designed furnace door incorporated into a mobile stand. The Inconel retort is mounted through the door and inserted into a 2500° F standard-box-type electric muffle furnace. The specimens were first cleaned and assembled and then placed into the retort. All connections were then made. The first step in providing the proper atmosphere was to thoroughly evacuate the retort, after sealing, to eliminate gaseous contaminants. The required vacuum or dry argon supply was then established while the retort was at room temperature. Dry argon dewpoint was maintained at −100° F or below. The vacuum was maintained below one micron. The retort was placed into the furnace by

Table 3—Brazing Parameters

Test No.	Parent metal	Brazing alloy	Alloy content	Temp., ° F	Time temp., min.	Test configuration	Remarks
AA	Inconel "X"	D	Approx. 1.5 oz/ft²	2150	None	Open face sandwich	Core 1/2-in. thick
	Inconel "X"	A	(plastic film)				
	Inconel "X"	B					
	Inconel "X"	C					
	René 41	D	Approx. 1.5 oz/ft²	2150	None	Open face sandwich	Core 0.8-in. thick
	René 41	A	(plastic film)				
	René 41	B					
	René 41	C					
AB	Inconel "X"	F	2-mil foil	1950	None	Open face sandwich	Core 1/2-in. thick
	Inconel "X"	E	2-mil foil	1950	None	Open face sandwich	Core 1/2-in. thick
	René 41	F	2-mil foil	1950	None	Open face sandwich	Core 0.8-in. thick
	René 41	E	2-mil foil	1950	None	Open face sandwich	Core 0.8-in. thick
AC	Inconel "X"	F	2-mil foil	2000	5	Open face sandwich	Core 1/2-in. thick
	Inconel "X"	E	2-mil foil	2000	5	Open face sandwich	Core 1/2-in. thick
	René 41	F	2-mil foil	2000	5	Open face sandwich	Core 1/2-in. thick
	René 41	E	2-mil foil	2000	5	Open face sandwich	Core 1/2-in. thick
AD	Inconel "X"	A	0.8 oz/ft²	2150	None	Sheets (for tensile tests)	Degradation tests
AE	Inconel "X"	E	2-mil foil	1950	5	Sheets (for tensile tests)	Degradation tests
AF	René 41	A	0.8 oz/ft² (sprayed)	2150	None	Sheets (for tensile tests)	Degradation tests

NOTE: Vacuum used in all cases.

Table 4—Brazing Results

Test No.	Parent metal	Brazing alloy	Results
AA	Inconel "X"	D	Visual—complete node flow, fillet formation lumpy in spots, fillets are small Micro—foil dissolved, no intergranular penetration, grains medium size, fillets fair to poor
	Inconel "X"	A	Visual—complete node flow, very satisfactory fillet formation, fillets are medium in size Micro—no intergranular penetration, foil partially dissolved, small fillets, diffusion into face sheet not excessive
	Inconel "X"	B	Visual—very granular in appearance, poor fillets, incomplete node flow
	Inconel "X"	C	Visual—same as B
	René 41	D	Visual—same as Inconel "X" with D Micro—foil 50% dissolved, slight amount of intergranular penetration, fillets small and not well formed
	René 41	A	Visual—fillet formation fair, some evidence of erosion, incomplete node flow Micro—foil partially dissolved, small but well formed fillets, no intergranular penetration, diffusion into base metal not excessive
	René 41	B	Very granular brazing alloy appearance, poor filleting, incomplete nodes
	René 41	C	Did not braze
AB	Inconel "X"	F	Top sheet of brazing alloy did not melt, bottom brazing alloy sheet melted. Poor braze, needs longer time or higher temperature
	Inconel "X"	E	Fillet formation good in most areas, node flow partial in some areas, complete in others, fair braze, requires longer time or higher temperature
	René 41	F	Same as Inconel "X" with F
	René 41	E	Alloy melted but fillet formation is poor; no node flow noted, poor braze, requires longer time or higher temperature
AC	Inconel "X"	F	Visual—fillet formation is small but complete, node flow is approx. 50%, added time at temp. seems to be required for optimum results Micro—no intergranular penetration, small but well formed fillets, foil partially dissolved
	Inconel "X"	E	Visual—good fillet formation, complete node flow, very good Micro—no intergranular penetration, fillet formation is good, foil partially dissolved
AC	René 41	F	Visual—fillet formation only fair, node flow is fair (only partial), added time or temperature is required Micro—foil dissolved about 50%, no intergranular penetration, fillet formation is good
	René 41	E	Visual—fillet formation fair, node flow is fair Micro—some intergranular penetration, fillets are poor

raising the door and wheeling the mobile platform into place. It was then allowed to heat and stabilize at 1400° F for $^1/_2$ hr. The temperature of the furnace heating chamber was then raised to that desired. The retort remained at temperature a specified length of time and was then removed from the furnace to air cool. Previous tests had established that the furnace temperature and the temperature within the working area of the retort were within 10° F. Vacuum or argon flow was maintained until the retort had cooled to below 200° F.

Twenty-five nickel-base and precious-base brazing alloys were initially selected for investigation. The first tests were made using small 1-in. sq open boxes, fabricated from both superalloys into which were placed the brazing alloy. In all cases the use of vacuum, when compared to dry argon produced cleaner results. The most appropriate alloys were then selected for further evaluation based upon visual inspection and examination of the microstructure. These are shown in Table 2. Vacuum was used solely for these tests.

Early in the program it was found that the booster pump used would not produce vacuum below 0.7 microns. This amount of vacuum was not sufficient to prevent the René 41 from developing an oxide film which interfered with brazing. A diffusion pump was then obtained which provided vacuum below 0.3 microns. This resulted in a clean brazed assembly. With powdered brazing alloys, a vacuum between 0.1 and 0.3 microns was usually obtained. With brazing alloy foil, vacuum below 0.1 micron was obtained. René 41 was observed to develop a very light metallic oxide luster at this vacuum. However this did not interfere with the brazing. Inconel "X" assemblies were found to be clean with the vacuum obtained with either the booster or diffusion pumps.

One-in. sq open face honeycomb sandwiches were used in tests AA through AC (Table 3) to further narrow the choice of brazing alloys. The nickel-base brazing alloys, available in powdered form only, were used at approximately 1.5 oz/ft^2. Precious-base brazing alloys were available in 2-mil thick foil. Results of tests AA through AC are shown in Table 4. Results of visual inspection and examination of the microstructure narrowed the choice to brazing alloy A for both Inconel "X" and René 41 and brazing alloy E for Inconel "X" only.

Heat Treatment Investigation and Results

Heat Treatments

The brazing temperature range should, if possible, be the same as the solution treatment temperature range of the superalloy in order to simplify the brazing and heat-treating cycles. A 1950° F brazing temperature for Inconel "X" with brazing alloy E and 2150° F brazing temperature for Inconel "X" and René 41 with brazing alloy A were found to produce satisfactory brazed joints. On this basis different heat treatments, following the brazing cycle, were investigated to determine the optimum brazing and heat-treating cycles for optimum mechanical properties:

Inconel "X" (brazed at 1950° F, 5 min at temp., air cooled).

1. Aged at 1400° F, 2 hr at temp; air cooled.
2. Aged at 1300° F, 20 hr at temp; air cooled.
3. Solution annealed at 1950° F, 12 min at temp., air cooled, plus aged at 1300° F, 20 hr at temp, air cooled.

Inconel "X" (brazed at 2150° F, no time at temp; air cooled).

1. Aged at 1400° F, 2 hr at temp; air cooled.
2. Aged at 1300° F, 20 hr at temp; air cooled.
3. Solution annealed at 1950° F, 12 min at temp; air cooled, plus aged at 1300° F, 20 hr. temp., air cooled.

René 41 (brazed at 2150° F, no time at temp, air cooled).

1. Aged at 1650° F, 4 hr at temp., air cooled.
2. Solution annealed at 1950° F, 12 min at temp., air cooled, plus aged at 1400° F, 16 hr., air cooled.

Superalloy test specimens without brazing alloy were processed together with test specimens containing brazing alloy. Heat-treatment tests are shown as AD through AF in Table 3. Results of these tests are shown in Table 4.

Inconel "X"

Vendor minimum guarantees for Inconel "X" sheet mill annealed and aged are 155 ksi for tensile ultimate and 100 ksi for tensile yield. However specimen AHT received in the mill annealed condition and aged of 1400° F for 2 hr gave low values of 128 ksi for tensile ultimate and 68 ksi for tensile yield. A solution anneal at 1950° F followed by an age of 1300° F for 20 hr (AHT-2) produced higher values, although still somewhat lower than the minimum guarantees.

Inconel "X"—Simulated Brazed at 1950° F

For Inconel "X" simulated brazed at 1950° F, an age following the brazing cycle produced higher mechanical properties (XN-1 and XN-2) than did a solution anneal followed by an age (XN-4). Aging at 1300° F for 20 hr (XN-2) produced slightly higher results than aging at 1400° F for 2 hr (XN-1) and was used to determine the effect of the braze alloy and braze heat cycle upon the mechanical properties of the superalloy.

Results showed that a solution anneal conducted in a salt bath (XN-4) was not comparable to the simulated braze heat cycle, although the specimens were well

Table 5—Tensile Test Results (Without Brazing Alloy)

Specimen identification	Condition	Ftu, ksi	Fty, ksi	Elong., %, 2 in.
Inconel "x"				
XN-1	Simulated braze at 1950° F, 5 min, ac, aged at 1400° F, 2 hr, ac	167.4	106.9	25.1
XN-2	Simulated braze at 1950° F, 5 min, ac, aged at 1300° F, 20 hr, ac	171.8	114.2	24.2
XN-2 (plus exposure)	Exposed 1 hr. at 1500° F	152.3	89.6	30.6
XN-2 (plus exposure)	Exposed 5 hr at 1500° F	153.5	87.6	79.2
XN-4	Simulated braze at 1950° F, 5 min, ac, sol'n annealed at 1950° F, 12 min, ac, aged at 1300° F, 20 hr, ac	156.7	99.3	23.3 (solution annealed in salt bath)
X30-1	Simulated braze at 2150° F, no time, ac, aged at 1400° F for 2 hr, ac	163.1	102.9	25.3
X30-2	Simulated braze at 2150° F, no time, ac, aged at 1300° F for 20 hr, ac	169.1	109.6	21.0
X30-2 (plus exposure)	Exposed 1 hr at 1500° F	150.1	85.8	24.8
X30-2 (plus exposure)	Exposed 5 hr at 1500° F	142.3	76.1	24.0
X30-4	Simulated braze 2150° F, no time, ac, sol'n annealed at 1950° F, 12 min, ac, aged at 1300° F, 20 hr, ac	137.5	96.3	12.2 (solution annealed in salt bath)
AHT	As rec'd plus aged at 1400° F for 2 hr	128.4	68.4	32.8
AHT-2	As rec'd plus sol'n—annealed at 1950° F, 12 min, ac, aged at 1300° F, 20 hr, ac	150.9	97.8	16.7 (solution annealed in salt bath)
Vendors heat-treated values (mill annealed and aged at 1300° F 20 hr at temp, ac)		155.0	100.0	20 (minimum)
René 41				
R30-1	Simulated braze at 2150° F, no time, ac, aged at 1650° F, 4 hr, ac	158.2	111.4	11.8
R30-2	Simulated braze at 2150° F, no time, ac sol'n annealed at 1950° F, 12 min, ac, aged at 1400° F, 16 hr, ac	170.3	134.6	7.2 (solution annealed in salt bath)
R30-2 (plus exposure)	Exposed 1 hr at 1800° F	142.3	81.6	20.0
R30-2 (plus exposure)	Exposed 5 hr at 1800° F	143.9	76.8	21.9
CHT	As rec'd plus sol'n annealed at 1950° F, 12 min, ac, aged at 1400° F, 16 hr, ac	179.6	152.1	6.5 (solution annealed in salt bath)
Vendors heat-treated values (mill annealed at 1950° F, 12 min at temp, ac, aged at 1400° F, 16 hr at temp, ac)		185.0	148.0	9

NOTE: All results are average of four tests.

protected from the effects of the salt. Apparently the combined effects of rapid heating and cooling and longer time at temperature were conducive in producing lower mechanical properties than that obtained during a simulated braze cycle, with its associated slower heating and cooling cycles and shorter time at temperature.

Inconel "X"—Simulated Brazed at 2150° F

For Inconel "X" simulated brazed at 2150° F, an age following the brazing cycle was also the preferred heat treatment, with the 1300° F treatment (X30-2) again giving slightly higher properties than the 1400° F treatment (X30-1). A solution anneal plus age following the 2150° F braze heat cycle again produced results that were lower than the vendor guarantees for sheet material which is mill annealed and aged.

No attempt was made to resolve the cause for the low mechanical properties of X30-4 and XN-4, since the age following the braze cycle was the preferred heat treatment and at the same time produced high mechanical properties.

Table 6—Tensile Test Results (with Brazing Alloy)

Specimen identification	Alloy	Condition	Ftu, ksi	Fty, ksi	Elongation, %, 2 in.
XN-2 (1-4)	Inconel "X"	Brazed at 1950° F, 5 min at temp, ac. Aged at 1300° F, 20 hr at temp, ac	154.4	102.0	18.5
XN-2 (5-8)		Same plus exposure at 1500° F for 1 hr	133.0	80.7	18.5
XN-2 (9-12)		Same plus exposure at 1500° F for 5 hr	Specimens damaged		
X30-2 (1-4)	Inconel "X"	Brazed at 2150° F, no time at temp, ac. Aged at 1300° F, 20 hr at temp, ac	145.9	104.3	13.1
X30-2 (5-8)		Same plus exposure at 1500° F, 1 hr, ac	136.0	83.8	18.9
X30-2 (9-12)		Same plus exposure at 1500° F, 5 hr, ac	119.3	77.6	11.2
R30-2 (1-4)	René 41	Brazed at 2150° F, no time at temp, ac. Sol'n annealed at 1950° F 12 min at temp, ac. Aged at 1400° F, 16 hr at temp, ac	137.7	119.2	2.9
R30-2 (5-8)		Same plus exposure at 1800° F for 1 hr	126.9	85.2	10.5
R30-2 (9-12)		Same plus exposure at 1800° F for 5 hr	128.2	72.7	19.7

Table 7—Mechanical Property Caused by Braze Alloy and Braze Cycle

Condition	Superalloy braze alloy	Ftu, ksi	Percent change	Fty, ksi	Percent change	Elongation, %, 2 in.
Simulated braze at 1950° F; 5 min, ac, aged at 1300° F, 20 hr, ac	Inconel "X" no braze alloy	171.8	...	114.2	...	24.1
Brazed at 1950° F; 5 min, ac, aged at 1300° F; 20 hr, ac	Inconel "X" Alloy E	154.4	—10.1	102.0	—10.7	18.5
Simulated braze at 2150° F; no time, ac, aged at 1300° F for 20 hr, ac	Inconel "X" no braze alloy	169.1	...	109.6	...	21.0
Brazed at 2150° F; no time, ac, aged at 1300° F for 20 hr, ac	Inconel "X" Alloy A	145.9	—13.7	104.3	—4.8	13.1
Simulated braze at 2150° F; no time, ac, sol'n. annealed at 1950° F; 12 min, ac, aged at 1400° F; 16 hr, ac	René 41 no braze alloy	170.3	...	134.6	...	7.2
Brazed at 2150° F; no time, ac, sol'n annealed at 1950° F; 12 min, ac, aged at 1400° F; 16 hr, ac	René 41 Alloy A	137.7	—19.1	119.2	—11.5	2.9

NOTE: All changes are lower except as noted.

René 41

Vendor typical properties for René 41 sheet solution annealed at 1950° F and aged at 1400° F for 16 hr are 185 ksi for tensile ultimate and 148 ksi for tensile yield. Mechanical properties obtained using a salt bath and protecting the specimens from the effects of the salt were 180 ksi for tensile ultimate and 152 ksi for tensile yield (CHT—Table 5).

For René 41 simulated brazed at 2150° F, the preferred heat treatment found was a solution anneal at 1950° F followed by an aging treatment at 1400° F. This is in agreement with that expected, that is, a lower solution annealing temperature produces higher mechanical properties. The solution anneal, following brazing at 2150° F accomplishes this.

Brazing-alloy Exposure Effects upon Base Metals

The amount of deterioration of the base metal due to brazing alloy, brazing cycle and exposure cycle was determined by brazing the alloy on one side of a tensile specimen. The brazing alloy was preplaced for a distance of 1 in. and located in the center portion of the 2-in. gage length. Figure 2 shows the step-by-step procedure in making the tensile coupons. The powdered, nickel brazing alloy was sprayed to form a narrow strip down the center of a 4- × 10-in. sheet. The spray solution was made by mixing acrylic cement with the powder. The correct amount of alloy placed on the specimens was determined by weighing. A weight of 0.8 oz/ft² for the tensile coupons was found to be equivalent to 2.0 oz/ft² for the sandwich. The 2.0 oz/ft² was previously found to provide sufficient brazing alloy for satisfactory fillet formation and node flow.

The method of preplacing the brazing alloy foil to the Inconel "X" sheet was done somewhat differently. This was necessary, since the precious metal brazing alloy flowed very freely and formed pools of alloy rather than being retained evenly over the center portion of the tensile specimen gage length. This was done by brazing a honeycomb sandwich panel and then sectioning it into two halves. The honeycomb was removed from the tensile coupons prior to testing.

The brazed tensile specimens were then sealed in stainless steel envelopes, which were evacuated to hold the envelope facings in intimate contact with the specimens. These were subjected to the heat

treatment selected previously. Four tensile coupons were cut from each tensile specimen. Coupon preparation and testing were done in accordance with Federal Test Method Standard No. 151a. Results of these tests are shown in Table 6. The effects of the brazing cycle resulted in degradation of the base metal and is shown in Table 7. Tables 5 and 6 are summarized in Table 7 which shows the percent change in tensile ultimate and tensile yield. A reduction of tensile ultimate of 10.1% and 10.7% respectively for Inconel "X" brazed with alloy E and 13.7% and 4.8% respectively for Inconel "X" brazed with alloy A resulted. A greater reduction (19.1 and 11.5% respectively) was found for René 41 brazed with alloy A.

Exposure of Inconel "X" and and René 41 tensile specimens, for times up to 5 hr, at 1500 and 1800° F respectively further reduced the tensile ultimate and tensile yield properties—Table 8. Exposures at temperatures were maintained in a partial vacuum to protect the brazed joint and in effect simulate actual service conditions.

The exposure temperatures in both cases were significantly higher than the aging temperatures. These were 200 and 400° F for Inconel "X" and René 41 respectively.

The harmful effect on base metals of the high temperatures required to perform the brazing operation reported by other investigations was experienced with René 41. However, recovery of the high mechanical properties was effected by a solution anneal and age treatment. No harmful effects were experienced with Inconel "X" after the brazing cycle and high mechanical properties were obtained by aging following brazing at 1950 or 2150° F. These results are summarized in Table 9.

Fabrication of Multilayer Specimens

A series of single and double corrugated, multilayer sandwich specimens were made to confirm the choice of brazing alloys. These are tabulated in Table 10. Figure 3 shows an exploded view of the components necessary to fabricate a sandwich having corrugations on each side. For the sandwiches using alloy A an amount of alloy equivalent to 2.0 oz/ft² was used. This was made up as a plastic film and sandwiched at the interfaces. For the sandwich using alloy E, a 2-mil foil was used. Originally it was decided to use a resistance welded corrugated sandwich with facings on both sides. This sandwich is similar in structure to a common corrugated paper box. The corrugated core and facings are joined by spot welds placed every $^1/_{32}$ in. in rows matching the pitch of the V-shaped core. A flat spot at the corrugation crests allows space for the spot welds which join the core to the facing sheets. Stiffening beads are formed into the sides of the core corrugations to increase the structural strength of the core and raise the structural efficiency of the sandwich. However, the structure could not be obtained in the superalloys required except in a production lot, which would have been too costly for the program. As an alternate an open-faced resistance-welded, corrugated structure was procured. For increased resistance to sonic vibrations it was decided to braze the face of the corrugated structure to the honeycomb and braze a facing sheet to the corrugations. Single and double corrugated, honeycomb sandwich specimens are shown

Table 8—Mechanical Property Caused Exposure

Condition	Superalloy braze alloy	Ftu, ksi	Percent change	Fty, ksi	Percent change	Elongation, %, 2 in.
Simulated braze at 1950° F; 5 min, ac, aged at 1300° F; 20 hr, ac, plus exposed at 1500° F; 1 hr	Inconel "X" no braze alloy	152.3	...	89.6	...	30.6
Brazed at 1950° F; 5 min, ac, aged at 1300° F; 20 hr, ac, plus exposed at 1500° F; 1 hr	Inconel "X" Alloy E	133.0	−12.7	80.7	−9.9	18.5
Simulated braze at 1950° F; 5 min, ac, aged at 1300° F; 20 hr, ac, plus exposed at 1500° F; 5 hr	Inconel "X" no braze alloy	153.5	...	87.6	...	29.2
Brazed at 1950° F; 5 min, ac, aged at 1300° F; 20 hr, ac, plus exposed at 1500° F; 5 hr	Inconel "X" Alloy E	Specimens damaged				
Simulated braze at 2150° F; no time, ac, aged at 1300° F for 20 hr, ac, plus exposed at 1500° F; 1 hr	Inconel "X" no braze alloy	150.1	...	85.8	...	24.8
Brazed at 2150° F; no time, ac, aged at 1300° F for 20 hr, ac, plus exposed at 1500° F; 1 hr	Inconel "X" Alloy A	136.0	−9.4	83.8	−2.3	18.9
Simulated braze at 2150° F; no time, ac, aged at 1300° F for 20 hr, ac, plus exposed at 1500° F; 5 hr	Inconel "X" no braze alloy	142.3	...	76.1	...	24.0
Brazed at 2150° F; no time, ac, aged at 1300° F for 20 hr, ac, plus exposed at 1500° F; 5 hr	Inconel "X" Alloy A	119.3	−16.1	77.6	+1.9	11.2
Simulated braze at 2150° F; no time, ac, sol'n annealed at 1950° F, 12 min, ac, aged at 1400° F; 16 hr, ac, plus exposed 1 hr at 1800° F	René 41 no braze alloy	142.3	...	81.6	...	20.0
Brazed at 2150° F; no time, ac, sol'n annealed at 1950° F, 12 min, ac, aged at 1400° F; 16 hr, ac plus exposed 1 hr at 1800° F	René 41 Alloy A	126.9	−10.9	85.2	+4.2	10.5
Simulated braze at 2150° F; no time, ac, sol'n annealed at 1950° F; 12 min, ac, aged at 1400° F, 16 hr ac plus exposed 5 hr at 1800° F	René 41 no braze alloy	143.9	...	76.8	...	21.9
Brazed at 2150° F; no time, ac, sol'n annealed at 1950° F, 12 min, ac, aged at 1400° F; 16 hr, ac plus exposed 5 hr at 1800° F	René 41 Alloy A	128.2	−10.9	72.7	−5.3	19.7

Table 9—Effects of Brazing Cycle on Mechanical Properties

Superalloy	Condition	Ftu, ksi	Fty, ksi	Elong., %, 2-in.
Inconel "X"	Normal heat treat[a]	170.0	115.0	25
	Simulated brazed at 1950° F and aged at 1300° F	171.8	114.2	24.1
	Simulated brazed at 2150° F and aged at 1300° F	169.1	109.6	21.0
René 41	Normal heat treat (Solution annealed at 1950° F and aged at 1400° F)	179.6	152.1	6.5
	Simulated brazed at 2150° F and aged at 1650° F	158.2	111.4	11.8
	Simulated brazed at 2150° F, solution annealed at 1950° F and aged at 1400° F	170.3	134.6	7.2

[a] Inconel "X," Technical Bulletin T-38 (Aug. '59), The International Nickel Co., (solution annealed at 2100° F and double aged at 1550° F and 1300° F respectively).

Table 10—Brazing Parameters

Test No.	Parent metal	Brazing alloy	Alloy content	Temp., ° F	Time at temp., min	Test configurations
AG	Inconel "X"	A	0.011 thick (approx. 2 oz/ft²) plastic film	2150	None	Single corrugated multilayer sandwich (2 x 2 in.)
	René 41	A	0.011 thick (approx. 2 oz/ft²) plastic film	2150	None	Single corrugated multilayer sandwich (2 x 2 in.)
AH	Inconel "X"	E	2-mil foil	1950	5	Single corrugated multilayer sandwich (2 x 2 in.)
AI	Inconel "X"	A	0.011 thick (approx. 2 oz/ft²) plastic film	2100	None	Single corrugated multilayer sandwich (2 x 2 in.)
	René 41	A	0.011 thick (approx. 2 oz/ft²) plastic film	2100	None	Single corrugated multilayer sandwich (2 x 2 in.)
AJ	Inconel "X"	E	2-mil foil	1950	5	Double corrugated multilayer sandwich (2 x 2 in.)
AK	Inconel "X"	A	2.0 oz/ft² at each joint	2150	None	Double corrugated multilayer (2 x 2 in.)
	René 41	A	2.0 oz/ft² at each joint	2150	None	Double corrugated multilayer (2 x 2 in.)
AL	Inconel "X"	E	2-mil foil	1950	10	Double corrugated multilayer (2 x 2 in.)
AM	Inconel "X"	A	2.0 oz/ft² at each joint	2150	None	Single corrugated $3^1/_2$ x $8^1/_2$ in.
AN	Inconel "X"	E	2-mil foil	1950	10	Single corrugated $3^1/_2$ x $8^1/_2$ in.
AO	René 41	A	2.0 oz/ft² at each joint	2150	None	Single corrugated $3^1/_2$ x $8^1/_2$ in.
AP	Inconel "X"	A	2.0 oz/ft² at each joint	2150	None	Double corrugated $3^1/_2$ x $8^1/_2$ in.
AQ	Inconel "X"	E	2-mil foil	1950	10	Double corrugated $3^1/_2$ x $8^1/_2$ in.
AR	René 41	A	2.0 oz/ft² at each joint	2150	None	Double corrugated $3^1/_2$ x $8^1/_2$ in.

NOTE: Vacuum used in all cases.

in Fig. 4. Results of visual examinations are tabulated in Table 11. An attempt to lower the brazing temperature from 2150 to 2100° F for the specimens brazed with alloy A resulted in incomplete node flow for the Inconel "X" and poorer fillet formation for René 41. Brazing was continued at 2150° F for the balance of the specimens. Brazing Inconel "X" with alloy E required a minimum of 5 min at 1950° F. Increasing the time to 10 min produced slightly better results and was selected for the balance of the specimens.

Metallurgical Evaluation

Inconel "X"

As previously discussed, lower values were obtained for specimens solution annealed plus aged following a simulated braze (XN-4 and X30-4) when compared with specimens aged only, after the simulated braze (XN-2 and X30-2). This difference was not resolved upon examination of the microstructure. Microstructures for specimens XN-2, XN-4, X30-2 and X30-4 were similar and normal for Inconel "X." As seen in Fig. 5, for XN-2 this consisted of well defined broken grain boundaries in a solid solution type matrix. There is a wide variation in the size of grains in different areas.

Inconel "X" (with Alloy A)

Specimen X30-2-1 brazed at 2150° F and subsequently aged, shown in Fig. 6, was very similar to Fig. 5. Exposure at 1500° F for 1 and 5 hr resulted in loss of grain definition, Figs. 7 and 8.

Inconel "X" (with Alloy E)

Specimen AHT 2 represents a normal microstructure for Inconel "X" solution annealed at 1950° F and subsequently aged at 1300° F. Figure 9 for specimen XN-2-1 is similar to AHT 2 with slightly larger grains, the result of slower heating to the 1950° F temperature during brazing. Exposure at 1500° F for 1 and 5 hr also resulted in a loss of grain definition as reported above for Inconel "X" and braze alloy A. Grain size at the braze interface was found to be larger than that on the opposite side of the sheet for both brazing alloys and was believed to have resulted in lower base metal strength.

Figure 10 is the microstructure of the brazed joint between the honeycomb core and the facing sheet for Inconel "X" and alloy E. Figure 11 is the microstructure of the brazed joint between the corrugated structure and the facing sheet for

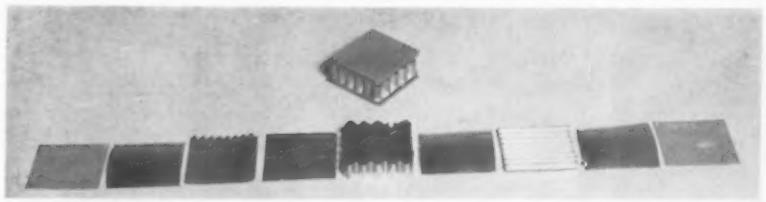

Fig. 3—Exploded view of multilayer sandwich

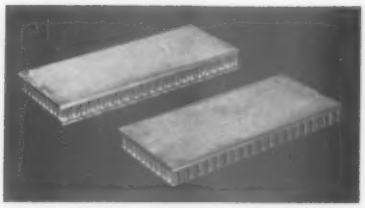

Fig. 4—Single and double corrugated honeycomb sandwich

Table 11—Brazing Results

Test No.	Parent metal	Brazing alloy	Results
AG	Inconel "X"	A	Visual—core very clean, fillet formation medium, complete node flow, slight evidence of erosion
AG	René 41	A	Visual—core slightly tarnished, fillet formation medium, some incomplete node flow, some evidence of erosion, outer surfaces of facings discolored
AH	Inconel "X"	E	Visual—fillet formation medium, complete node flow no evidence of erosion
AI	Inconel "X"	A	Visual—fillet formation medium, incomplete node flow some discoloration on facing sheets
AI	René 41	A	Visual—all surfaces were discolored, fillet formation not as good as AG, incomplete node flow
AJ	Inconel "X"	E	Visual—fillet formation not as satisfactory as AH, incomplete node flow
AK	Inconel "X"	A	Visual—fillet formation medium, complete node flow, core clean, some discoloration outer surface of top face
AK	René 41	A	Visual—light oxide coating on all surfaces, fillet formation medium, incomplete node flow some evidence of erosion noted

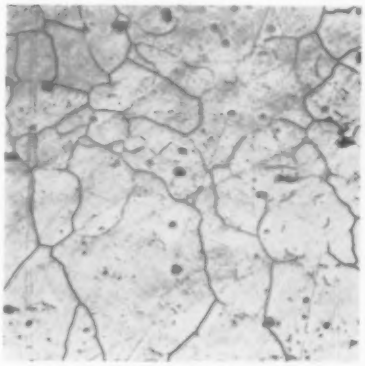

Fig. 5—Inconel "X" simulated brazed at 1950° F and aged at 1300° F

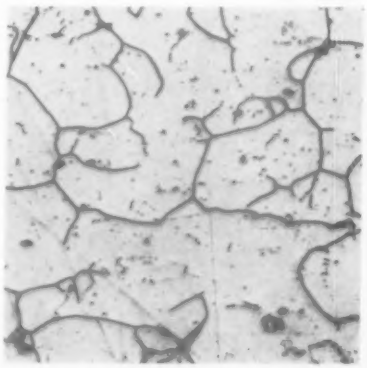

Fig. 6—Inconel "X" brazed at 2150° F and aged at 1300° F

the same superalloy-braze alloy combination. Both microstructures are typical of similar Inconel "X" and René 41 joints brazed with alloy A.

René 41

Normal microstructure for René 41 solution annealed at 1950° F and aged at 1400° F consists of fine, discrete, dispersed particles of carbide in a solid solution matrix. Figure 12 shows the microstructure for specimen CHT. Note the considerable amount of twinning. The large grains were found predominantly in the center portion of the sheet, with the smaller grains very close to the surface of the sheet. Islands of carbides are dispersed throughout the structure with the large, less numerous TiC seen as white islands whereas the small M_6C are gray in appearance. The M_6C carbides are also located in the grain boundaries.

The more than normal amount of twinning could be the result of a short time (12 min) at the solution annealing temperature of 1950° F.

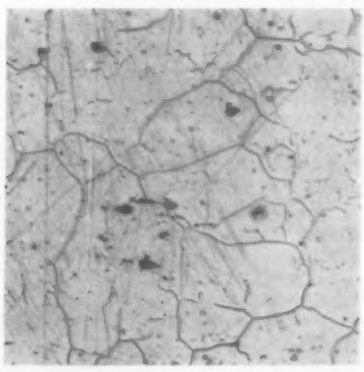

Fig. 7—Inconel "X" brazed at 2150° F, aged at 1300° F and exposed 1 hr at 1500° F

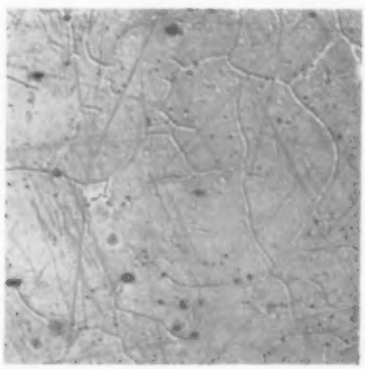

Fig. 8—Inconel "X" brazed at 2150° F, aged at 1300° F and exposed 5 hr at 1500° F

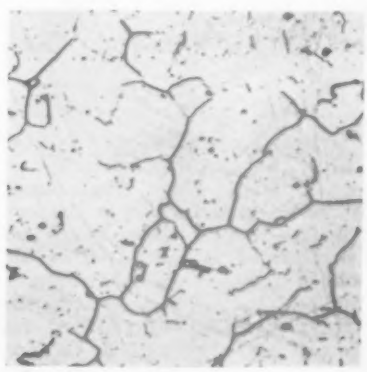

Fig. 9—Inconel "X" brazed at 1950° F and aged at 1300° F

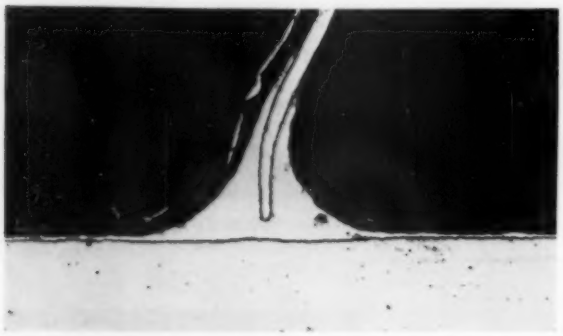

Fig. 10—Inconel "X" core to face joint brazed with alloy E

Fig. 11—Inconel "X" corrugation to face joint brazed with alloy E

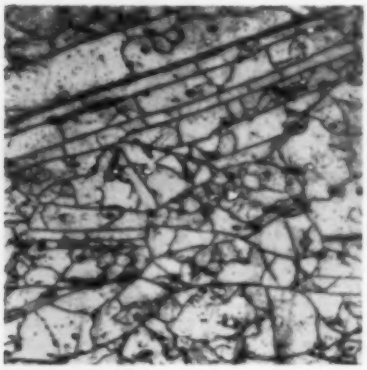

Fig. 12—René 41 solution annealed at 1950° F and aged at 1400 ° F

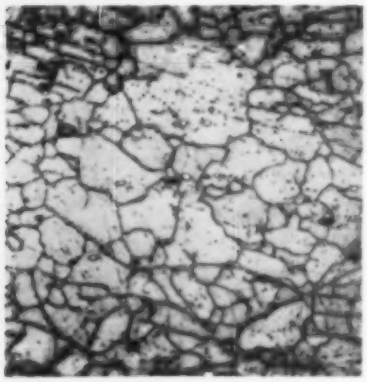

Fig. 13—René 41 simulated brazed at 2150° F, solution annealed at 1950° F and aged at 1400° F

Figure 13 is typical of the hardened René 41 microstructure showing much less twinning. Again small grains are concentrated at the surface, whereas the larger grains are concentrated at the center of the sheet. Exposure at 1800° F for 1 and 5 hr resulted in delineating the grain boundaries as reported for Inconel "X" at 1500° F. Carbide islands remain randomly dispersed throughout the matrix.

The brazing alloy modified the

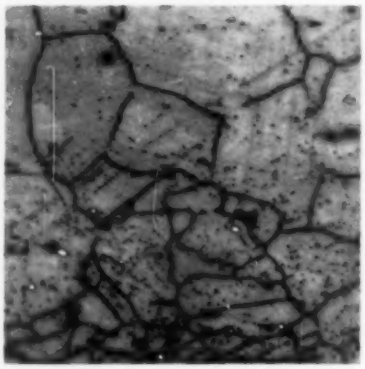

Fig. 14—René 41 brazed joint simulated brazed at 2150° F solution annealed at 1950° F and aged at 1400° F

René 41 microstructure and contributed to the fairly large reduction in mechanical properties. Figure 14 shows the microstructure for the brazed joint following solution anneal at 1950° F and age at 1400° F. Large grains appear adjacent to the interface whereas smaller grains appear on the opposite side of the sheet. The larger grains are believed to be the major cause for lower mechanical properties. Exposure at 1800° F for 1 and 5 hr does not reduce the grain size. However, a darkening of the structure was noted at the 5 hr exposure. This darkening was apparently the Ni_3 (Al, Ti) compound precipitate which is visible during overaging.

Summary of Results

1. A satisfactory vacuum furnace brazing technique has been developed for fabricating multilayer sandwich panels using Inconel "X" and René 41 superalloys.

2. A nickel base, chromium-silicon brazing alloy was found satisfactory for both Inconel "X" and René 41 brazed at 2150° F and a copper base, gold-nickel brazing alloy was found satisfactory for Inconel "X" brazed at 1950° F.

3. For Inconel "X" brazed at 1950 and 2150° F, aging following the brazing cycle produced higher mechanical properties than solution annealing followed by aging. For René 41 brazed at 2150° F, preferred treatment was a solution anneal at 1950° F followed by an aging at 1400° F.

4. Base metal strengths were lowered by the effects of the brazing alloy, brazing cycle and exposure; however, significant strength levels were maintained.

Discussion and Recommendations

Development of a satisfactory technique for fabricating Inconel "X" and René 41 multilayer sandwich structures was achieved using vacuum furnace brazing and commercially available brazing alloys. Although the strength of the superalloy was lowered by the effects of the brazing alloy in all cases and by as much as 19% for René 41, usable strengths were maintained. The effects of exposures in this program includes the effect of overaging of the superalloys and should be considered when reviewing the results. Although design criteria, based upon edgewise compression, flatwise compression, flexure and dynamic tests, were originally a part of this program, time limitations prevented their initiation. Such tests both at room and elevated temperatures are necessary before usable structures could be designed.

The selection of the brazing alloys should by no means be considered complete. Other alloys should be considered to minimize reduction of base metal strength. Future work may require development of special brazing alloys having unique characteristics for successful brazements to be used in hypervelocity structures.

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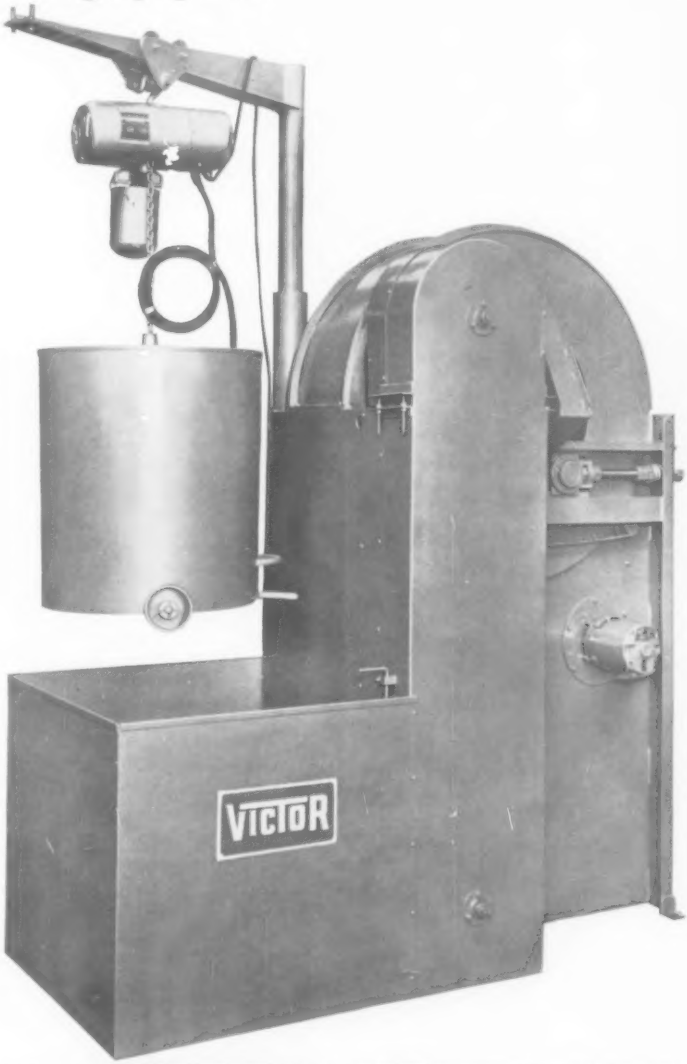
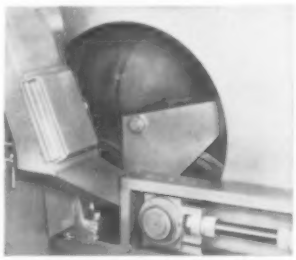
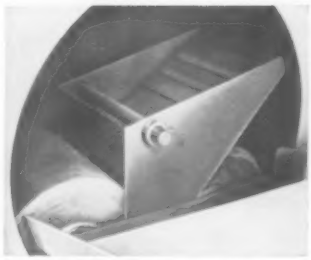


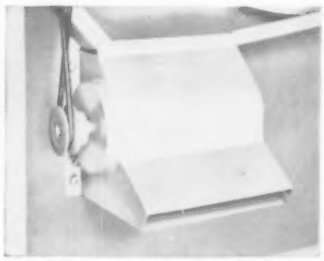
HOW VICTOR FREES FLUX AND TRAPS METALS



Primary magnetic separator removes most of loose metal as used flux feeds into crusher rolls. Hinged cover lifts for easy cleaning.



Here two hardfaced rollers crush fused flux, thus freeing all metal so second magnetic separator can pick it up as flux flows on.



Final magnetic separator at output spout catches last remaining metal particles. No wonder the Victor makes re-usable such a high percentage of fused and used flux.

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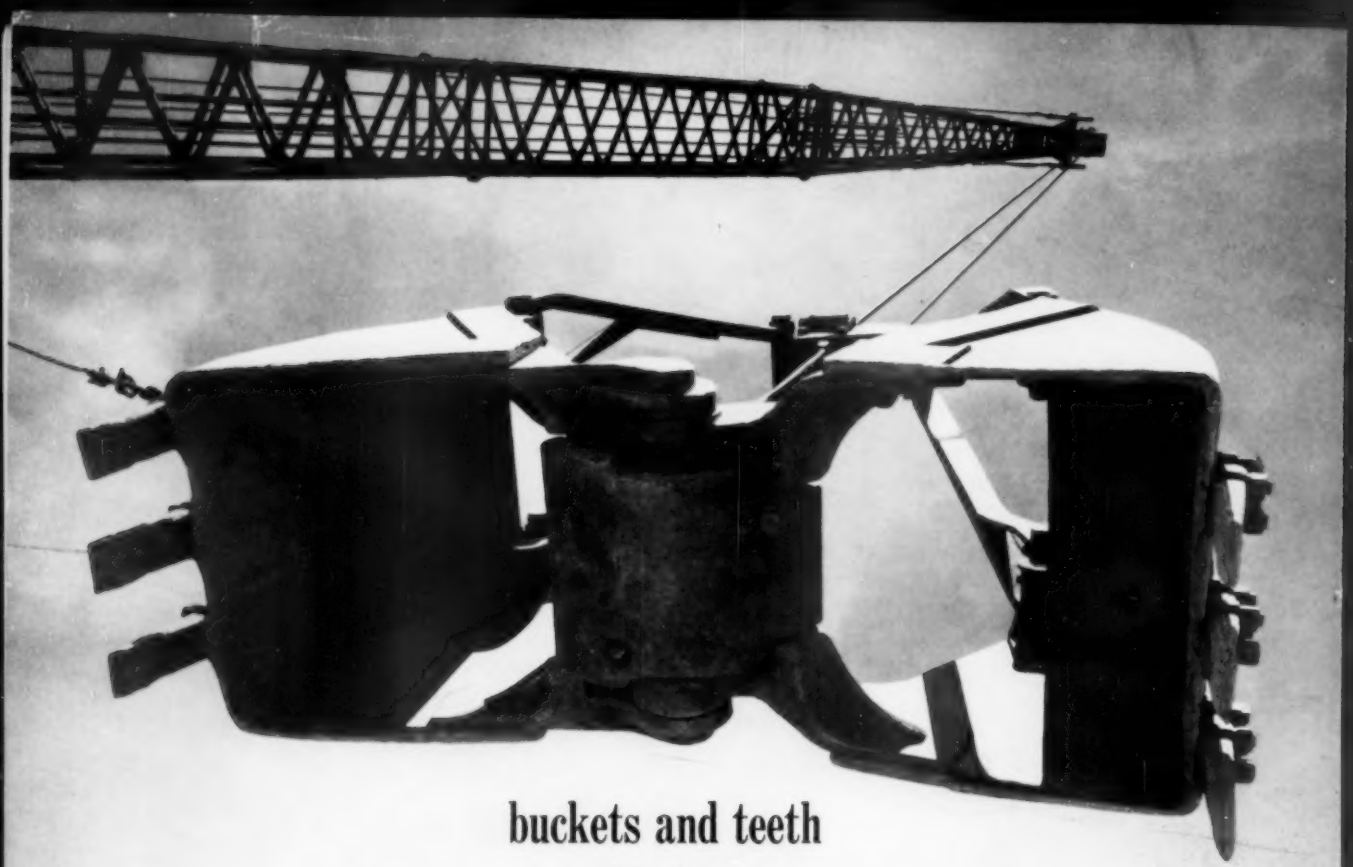

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